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Evaluation of Different Levels of Exogenous Hydrophilic Emulsifier Supplementation in Swine Diets

양돈사료 내 친수성 유화제의 수준별 첨가효과

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Overall Summary

Evaluation of Different Levels of Exogenous Hydrophilic Emulsifier Supplementation in Swine Diets

Dietary exogenous hydrophilic emulsifier (SOLMAX®50, KIMIN INC., Korea) consisted of sodium stearoyl-2-lactylate (SSL) that had a hydrophilic characteristic which was easily dissolved in water because metabolism of gastrointestinal tract in the body was occurred based on the water. The value of HLB for SOLMAX®50 is about 20, which is the most hydrophilic emulsifier in the current emulsifier market (Choi, 2014).

The objectives of these experiments were to investigate the effects of exogenous hydrophilic emulsifier supplementation 1) on growth performance, blood profiles and nutrient digestibility in weaning pigs, 2) on reproductive performance, litter performance and blood profiles in lactating sows and 3) on apparent ileal nutrient digestibility in growing pigs.

Experiment I. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Growth Performance, Blood Profiles and Nutrient Digestibility in Weaning Pigs

This study was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on growth performance, blood profiles and nutrient digestibility in weaning pigs. A total of 80 weaning pigs ([Yorkshire × Landrace] × Duroc), body weight (BW) = 7.22 ± 0.23 kg; weaned at day 28 ± 3) were randomly allotted to one of four treatments in a randomized complete block (RCB) design in 5 replicates with 4 pigs per pen. Dietary treatments were divided by the supplementation level of emulsifier; 1) Control : corn-SBM based diet (3,265kcal of

ME/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier, 4) E0.15 : basal diet + 0.15% emulsifier. The phase I (0-2^{nd} wk after weaning) diet contained 3,265 kcal of ME/kg and 23.70% crude protein and phase II (3^{rd}–5^{th} wk after weaning) diet contained 3,265 kcal of ME/kg and 20.90% crude protein, respectively. Diets were provided *ad libitum* during the whole experimental period. All other nutrients were met or exceeded requirements of NRC (1998). There were no significant differences in BW, ADG, ADFI, and G:F ratio during phase I. However, ADG during the whole experimental period was increased as hydrophilic emulsifier level increased (linear, P=0.01). Also G:F ratio during entire experimental period was increased as hydrophilic emulsifier level increased (linear, P<0.01), and the results of E0.05, E0.10 and E0.15 treatments during phase II were differed significantly compared to those in control diet (P=0.02). There were no significant differences in total cholesterol, triglyceride, LDL and HDL cholesterol concentrations on phase I. However, in phase II, there was a quadratic response (quadratic, P<0.01) in total cholesterol, LDL cholesterol and HDL cholesterol concentrations as hydrophilic emulsifier level increased and the results in E0.10 were reduced compared to those in control, E0.05 and E0.15 regarding total cholesterol (P<0.01), LDL cholesterol (P<0.01) and HDL cholesterol concentrations (P=0.02). The nutrient digestibilities of dry matter, crude protein and crude ash were not affected by dietary treatments. But there was a quadratic effect on crude fat digestibility as hydrophilic emulsifier level increased (quadratic, P=0.01), and the results in E0.05, E0.10 and E0.15 treatment were significant different compared to those in control diet (P<0.01). Consequently, these results demonstrated that 0.05% of exogenous hydrophilic emulsifier supplementation in diet contributed positive effects on growth performance, specially G:F ratio and fat digestibility in weaning pigs.

Key words: Exogenous Hydrophilic Emulsifier, Growth Performance, Blood Profiles, Nutrient Digestibility, Weaning Pigs

Experiment II. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Reproductive Performance, Litter Performance and Blood Profiles in Lactating Sows

This experiment was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on reproductive performance, litter performance and blood profiles in lactating sows. A total of 40 multiparous sows (F1, Yorkshire x Landrace; Darby, Korea) with an initial BW of 248.6 ± 19.71 kg were allotted to one of four treatments with a 2 x 2 factorial arrangement. The first factor was energy level in diet (3,200 or 3,265 kcal of ME/kg), and the second factor was inclusion of emulsifier (SOLMAX®50, KIMIN INC., Korea). The experimental diets containing different energy level and with or without supplementation of 0.05% emulsifier was supplied in lactation. All other nutrients were met or exceeded the requirements of NRC (1998), and sows were fed experimental diets *ad libitum* with a free access to waterer during lactation period after 5 days postpartum. During the whole experimental period, there were no significant differences in body weight, body weight change (0-21d), backfat thickness, backfat change (0-21d), feed intake and WEI in lactating sows. Although litter weight and litter weight gain were not affected by supplementation of emulsifier, reproductive performance and litter growth tended to have an interaction between energy and emulsifier in piglet weight gain during lactation period (ME x E interaction, P=0.10). In blood profiles, glucose, insulin, total protein and creatinine level in sows were not affected by dietary treatments. But there was tendency for an interaction between energy and emulsifier on PUN concentration of lactating sows (ME x E interaction, P=0.06). Also there was a significant interaction between energy and emulsifier on albumin concentration of sows (ME x E interaction, P=0.02). There were no effects on total cholesterol, triglyceride, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol and free fatty acid level by dietary treatments in lactating sows. But concentration of triglyceride and VLDL-cholesterol at 21 d of lactation was decreased when sows were fed diet containing 3,200 kcal of ME/kg (Energy, P=0.06, P=0.05, respectively). The results of blood profiles in piglet at 21d of lactation were not affected by dietary treatments. Moreover, total cholesterol, triglyceride, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol and free fatty acid concentration in piglet were not affected by dietary treatments. The colostrum and milk compositions such as milk fat, casein, protein, lactose, total solid and solids-not-fat were not affected by dietary treatments. Consequently, these results demonstrated that 0.05% of exogenous hydrophilic emulsifier supplementation in low energy diet (3,200 kcal of ME/kg) had positive effects on litter performance, particularly piglet weight gain in lactating sows.

Key words : Litter performance, Blood profiles, Emulsifier, Lactating sows

Experiment III. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Apparent Ileal Nutrient Digestibility in Growing Pigs

This study was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on apparent ileal nutrient digestibility in growing pigs. A total of 9 crossbred growing pigs ([Yorkshire × Landrace] × Duroc, average body weight (BW) : 22.95 ± 1.45kg) were allotted to each treatment in an individual metabolic crate to collect feces and urine separately in a completely randomized design (CRD) with 3 replicates per treatment. Treatments were : 1) Control : corn-SBM based diet with 3% tallow (ME 3,265 kcal/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier. All other nutrients in experimental diet were met or exceeded the NRC requirement (1998). The experimental diets were provided twice daily at 07:00 and 19:00. In the results of the essential amino acids, the AID of lysine was increased as hydrophilic emulsifier level increased (linear, P<0.01). In addition, the AID of methionine and threonine were increased as hydrophilic emulsifier level increased

(linear, $P=0.03$ and quadratic, $P=0.01$, respectively). However, the result in E0.05 treatment was differed significantly compared to that in control diet. Also, the AID of valine was increased as hydrophilic emulsifier level increased (quadratic, $P<0.01$) and the result in E0.05 treatment was significantly different compared to control treatment. The AID of saturated fatty acid was increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P=0.03$) and the results in E0.05 and E0.10 treatments had a highly significant difference compared to those in control treatment ($P<0.01$). Among the saturated fatty acids, the AID of myristic acid (C14:0) was increased as hydrophilic emulsifier level increased (linear, $P=0.04$; quadratic, $P=0.02$) and the results in E0.05 and E0.10 treatments had a significant difference compared to control treatment ($P=0.02$). The AID of palmitic acid (C16:0), heptadecanoic acid (C17:0) and stearic acid (C18:0) were increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P<0.01$). Regarding the AID of unsaturated fatty acids, there were no detectable effects on the AID except oleic acid (C18:1). The AID of oleic acid (C18:1) was increased as hydrophilic emulsifier level increased (quadratic, $P=0.02$) and the result in E0.05 treatment was significantly different compared to control treatment. Consequently, these results demonstrated that exogenous hydrophilic emulsifier supplementation improved the apparent ileal digestibility of amino acids and fatty acids, particularly essential amino acids and saturated fattty acids in growing pig.

Key words: Exogenous Hydrophilic Emulsifier, Apparent Ileal Nutrient Digestibility, Growing Pigs

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List of Abbreviation

AA	:	Amino acid
ADG	:	Average daily gain
ADFI	:	Average daily feed intake
AID	:	Apparent ileal digestibility
AOAC	:	Association of official analytical chemists
ATTD	:	Apparent total tract digestibility
BW	:	Body weight
CCK	:	Cholecystokinin
CP	:	Crude protein
CRD	:	Completely randomized design
DM	:	Dry matter
EE	:	Ether extract
FA	:	Fatty acid
FCR	:	Feed conversion ratio
FDA	:	Food and Drug Administration
GE	:	Gross energy
HDL	:	High-density lipoprotein
HLB	:	Hydrophilic lipophilic balance
LCFA	:	Long Chain Fatty Acid
LDL	:	Low-density lipoprotein
NRC	:	National Research Council
MCFA	:	Medium Chain Fatty Acid
ME	:	Metabolizable energy
PUN	:	Plasma Urea Nitrogen
RCB	:	Randomized complete block
SAS	:	Statistical Analysis System
SBM	:	Soybean meal

SCFA	:	Short Chain Fatty Acid
SFA	:	Saturated fatty acid
SSL	:	Sodium stearoyl-2-lactylate
SSL	:	Sodium stearoyl-2-lactylate
UFA	:	Unsaturated fatty acid
USDA	:	United States Department of Agriculture
VLDL	:	Very low density lipoprotein
WEI	:	Wean to estrus interval

Chapter I. General Introduction

Fat has high energy value and it is an expensive source in animal feed formulation (Choi, 2014). Commercial feeds are often supplemented with fats to provide a diet with sufficient energy (Gabbrielle, 2010). Supplementation of fats will reduce the dust of feeds and can improve palatability (Choi, 2014). The use of fats and oils in swine diet as an energy source has become a wide spread practice in the feed industry (Gabbrielle, 2010), so fat absorption and digestion in pig is very important (Gabbrielle, 2010).

The gastrointestinal tract (GIT) of a pig is a complex environment (De Lange *et al*., 2010). Piglets suffering post-weaning stress showed a reduced feed intake and a shift in the partitioning of dietary nutrients away from skeletal muscle development toward a metabolic response to support the immune system, resulted in accelerating lipolysis and muscle protein degradation (Moon, 2012). Weaning typically influences physiological responses in young pig, particularly intestinal function and secretion (Cera *et al*., 1990). Cera *et al*. (1988a) found there were the decreased villi height and morphological changes after weaning. Weaning piglets secrete bile in very small amounts and have limited ability for emulsification (Jones *et al*., 1991). Bile salts acted to emulsify fat to form the micelles to help absorption from the intestinal tract (Gabbrielle, 2010). However, the production and utilization of bile salts in animal is very limited at birth and during early development stages (Orban and Harmon, 2000). When the fat content of piglet diets is high, exogenous emulsifier supplementation may improve fat digestibility (Jones *et al*., 1991; Overland *et al*., 1993; Soares and Lopez-Bote, 2002;).

During lactation period, sows may have negative energy and nutrient balance because lactating feed intake is insufficient to their nutrients requirement for milk production (Mullan and Williams, 1989; Yang *et al*., 1989). Therefore, addition of fat into a diet for lactating sow is very important because provided energy from the added fat is associated with milk production, litter performance and subsequent performance of pigs during nursery and growing –fattening period

(Quiniou *et al*., 2008).

Polin (1980) indicated that fat digestibility was increased when fat mixed with emulsifier before it was fed to broiler. Dietary exogenous hydrophilic emulsifier up to 0.05% in broiler diet might have beneficial influences on growth performance and feed efficiency without any deleterious effects on apparent total tract digestibility of nutrients although basal diet contained low energy (Choi, 2014).

An emulsifier with a hydrophilic head and a lipophilic tail is a substance that stabilizes an emulsion by decreasing the surface tension (Choi, 2014). The hydrophilic head is directed to the aqueous phase and the hydrophobic tail to the oil phase. This structural characteristic can help the fat digestion in animal body (Davis, 1994). The emulsification process of emulsifiers is to increase the surface area of fats by breaking the large fat globules, and this process may help the action of lipase (McGlone and Pond, 2003). Emulsification is an essential step for fat digestion (McGlone and Pond, 2003). Fat with emulsifier in the gastrointestinal tract can make smaller fat droplets and decrease the size of micelles before absorption and thereby increasing fat digestibility (Choi, 2014).

Dietary exogenous hydrophilic emulsifier (SOLMAX®50, KIMIN INC., Korea) consisted of sodium stearoyl-2-lactylate (SSL) that had a hydrophilic characteristic which was easily dissolved in water because metabolism of gastrointestinal tract in the body was based on the water. The value of HLB for SOLMAX®50 is about 20, which is most hydrophilic emulsifier in the current emulsifier market (Choi, 2014). For a long time, SSL is widely used as a food emulsifier in a food industry but it is becoming a new molecule in feed industry. Therefore, more research regarding effects of hydrophilic emulsifier supplementation was needed to apply in the feed industry (Choi, 2014).

In current study, three experiments were conducted to investigate the effects of exogenous hydrophilic emulsifier supplementation 1) on growth performance, blood profiles and nutrient digestibility in weaning pigs, 2) on reproductive performance, litter performance and blood profiles in lactating sows and 3) on apparent ileal nutrient digestibility in growing pigs.

Chapter II. Review of Literature

1. Fat digestion in pigs

1.1 General digestive physiology and fat digestion in pig

The gastrointestinal tract (GIT) of a pig is a complex environment (De Lange *et al*., 2010). In other words, gut physiology, immunology, body functions and health are basic to solve the problems of dietary change and post-weaning growth retardation (Davide, 2012). Piglets suffering post-weaning stress showed a reduced feed intake and a shift in the partitioning of dietary nutrients away from skeletal muscle development toward a metabolic response to support the immune system, resulted in accelerating lipolysis and muscle protein degradation (Moon, 2012). Cera *et al*. (1988a) indicated that there were the decreased villi height and morphological changes after weaning. This response was most dramatic at earlier weaning ages (Cera *et al*., 1988a). Nutrient absorption, therefore, in addition to enzyme secretion, likely is influenced by weaning age and diet composition (Salah *et al*., 2014). Hampson (1986) reported that there were highly significant differences in crypt depth and complexity of villi morphology with a big reduction in villi height in weaned pigs compared to unweaned pigs.

Weaning is a major critical period of pig rearing because of increased susceptibility to gut disorders, infections and diarrhea (Jean-Paul LALLÈS *et al*., 2004). Weaning piglets secrete bile in very small amounts and have limited ability for emulsification (Jones *et al*., 1991). Early weaned pigs are less capable of digesting and utilizing dietary fat than older pigs are (Pettigrew and Moser, 1991). Bile salts acted to emulsify fat to form the micelles to help absorption from the intestinal tract (Gabbrielle, 2010). However, the production and utilization of bile salts in animal is very limited at birth and during early development stages (Orban and Harmon, 2000). As shown in Figure 1, enzyme activity (gastric lipase, pancreatic lipase, colipase, and carboxyl ester hydrolase) are affected by age and body weight (Jensen *et al*., 1997).

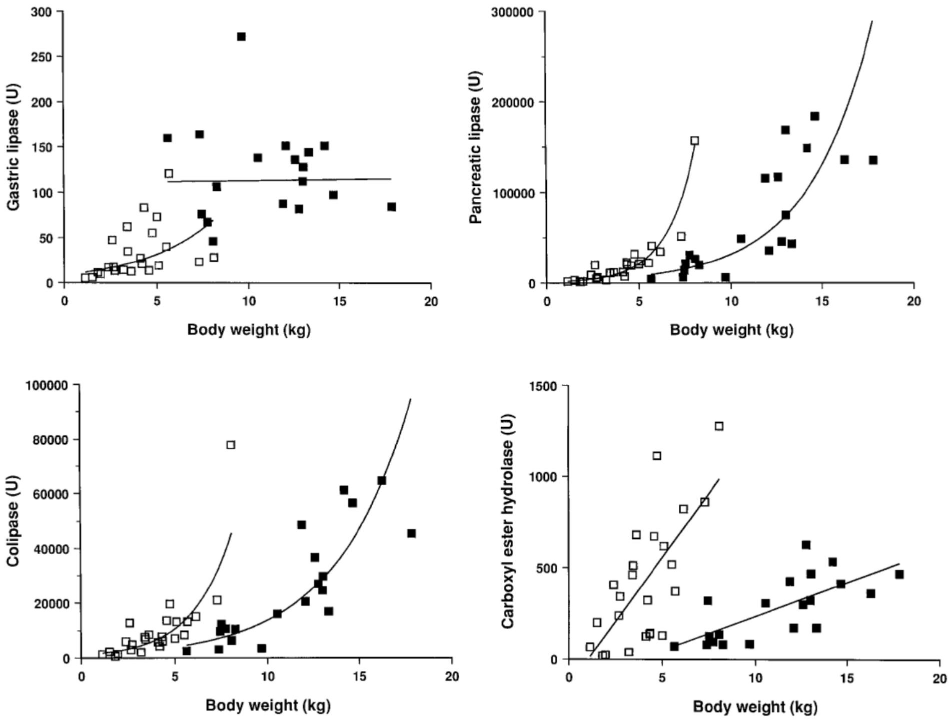


Figure 1. The activity of gastric lipase, pancreatic lipase, colipase, and carboxyl ester hydrolase in relation to the BW of pigs pre-weaning (□) and post- weaning (■) (Jensen *et al.*, 1997).

Dietary fat is hydrolyzed in the gastrointestinal tract by lipolytic enzymes secreted from the stomach or pancreas (Gu *et al.*, 2003). The total lipase activity in stomach tissue with an optimum pH of 6.2 is only about 3% of that found in the pancreas, although 25–50% of dietary lipid in newborn pigs could be hydrolyzed in the stomach to diacylglycerols, monoacylglycerols and free fatty acids (Newport and Howarth, 1985). Liu *et al.* (2001) also demonstrated that gastric lipase increased slowly before reached 21 d of age, and then the total activity of gastric lipase at 28 d was significantly higher than that at 21 d. However, the specific and total activity of gastric lipase were less than those of pancreatic lipase (Liu *et al.*, 2001). Therefore, the major process of fat digestion occurs in the small intestine.

The fat in the small intestine encourages the release of the CCK to secrete bile into the small intestine (Gabbrielle, 2010)

The action of bile is to break down large fat globules into small fat size, so that pancreatic lipase can break down the triacylglyceride into free fatty acids and mono- and diacylglycerides (Gabbrielle, 2010). Pancreatic lipase level and activity are very low until the piglet receives nutrients by suckling (Jack *et al*., 2014). Once the piglet sucks, pancreatic lipase increased significantly, especially from 14 d to 28 d of age (Liu *et al*., 2001; Fig. 2).

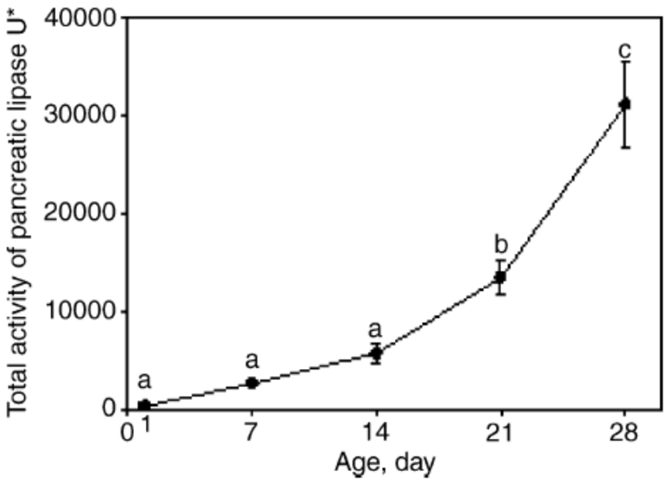


Figure 2. Development of pancreatic lipase activity in nursing piglets.
Means without common letters(a-c) differ significantly($p<0.05$) (Liu *et al*., 2001)

Corring *et al*. (1978) observed that pancreatic lipase activity in the piglet for 8 weeks of age increased as the piglet grew. Cera *et al*. (1990) reported that pancreatic lipase activity in suckling piglets increased significantly from 2 d to 35 d and weaning at 21 d followed to reduce into 3 days postweaning and then increased linearly. Piglets showed different fat digestibility depending on fat source and age of piglet (Table 1, Cera *et al*., 1988b).

Table 1. Various fat sources and fat digestibility(%) by age in weaning pigs (Cera *et al.*, 1988b)

Fat type	Weeks after weaning			
	1	2	3	4
Tallow	64.82	72.36	81.82	82.48
Lard	68.12	71.76	83.55	84.90
Corn oil	78.96	80.48	89.82	88.79

1.2 Importance of fat digestibility in sows

The nutritional requirements of the modern lactating sow have increased continuously because of genetic improvements for litter size (Boyd and Kensinger, 1998). During lactation period, sows may have negative energy and nutrient balance because lactating feed intake is insufficient to their nutrients requirement for milk production (Mullan and Williams, 1989; Yang *et al.*, 1989). Insufficient consumption of nutrients will lead to tissue mobilization from the body in an attempt to maintain milk production because lactation is a first priority (Pettigrew and Moser, 1991). Fat supplementation to lactating sow diets is very important to minimize body fat loss during lactation period (Pettigrew and Moser, 1991). Also fat supplementation to lactating sow diets is associated with milk production, litter performance and subsequent performance of pigs during nursery and growing-fattening period (Quiniou *et al.*, 2008).

2. Dietary fat in pigs

2.1. Fat

The term ‘fat’ is applied to those foods or components of foods that are clearly fatty in nature, greasy in texture and immiscible with water (Gurr, 1984). The difference between fats and oils is the physical form at room temperature. Fats and oils has different form at room temperature such as solid and liquid. Fat has about 2.25 times as much more energy as the carbohydrates in grain. It is a very condensed energy source when supplemented to animal diets to increase the energy density of the feed. Supplementation of fats will reduce the dust of feeds and can improve palatability (Choi, 2014). Scientists use the more general term 'lipid' to describe a chemically diverse group of biological substances that are generally hydrophobic in nature and in many cases soluble in organic solvents (Smith, 2000). However, for the purpose of comprehensive classification, lipids are defined as hydrophobic or amphipathic small molecules (Fahy *et al.*, 2005). Lipids may be categorized based on their chemically functional backbone in Table 2.

Table 2. Lipid categories and examples (Fahy *et al.*, 2005)

Category	**Abbreviation**	**Example**
Fatty acids	**FA**	dodecanoic acid
Glycerolipids	**GL**	1-hexadecanoyl-2-(9 *Z* -octadecenoyl)-*sn* -glycerol
Glycerophospholipids	**GP**	1-hexadecanoyl-2-(9 *Z*-ocSTtadecenoyl)-*sn*-glycero-3-phosphocholine
Sphingolipids	**SP**	*N*-(tetradecanoyl)-sphing-4-enine
Sterol lipids	**ST**	cholest-5-en-3-ol
Prenol lipids	**PR**	2*E*,6*E*-farnesol
Saccharolipids	**SL**	UDP-3-*O*-(3*R*-hydroxy-tetradecanoyl)-_d-*N*-acetylglucosamine
Polyketides	**PK**	aflatoxin B_1

Frobish *et al.* (1970) observed that addition of fat to the diet didn't improve consistently either gain or feed efficiency. Among the fat sources, coconut oil and butter were utilized more efficiently; lard, corn oil and soybean oil were intermediate (Frobish *et al.,* 1970). Frobish *et al. (*1969) found that addition of fat to the diet of baby pigs results in a decrease in growth and an increase in energy required per unit of gain. Sewell and Miller (1965) also observed that the addition of fat to the diet of pigs 21 days old resulted in a significant reduction in the feed required per unit of gain. Eusebio *et al.* (1965) who demonstrated that increasing the level of fat in the diet improved neither weight gain nor feed efficiency. The discrepancy may be partially because of the age of pigs used and the type (Eusebio *et al.,* 1965).

2.2. Dietary fat levels and sources in pigs

The commonly used fat sources in animal feed are presented in Table 3. There are the animal fat (lard, tallow, poultry fat), feed grade vegetable fat sources (soybean oil, canola oil, corn oil, coconut oil, rapeseed oil, palm oil, palm oil mix, and sunflower oil, etc) and marine fat sources (fish oil) (NRC, 1998).

Table 3. Different fat source and its categories (NRC, 1998)

Animal fat	Include rendered fats from beef or pork by-products (tallow, lard and grease)
Poultry fat	Includes fats from 100 % poultry offal
Mixed feed grade	Blends of tallow, grease, poultry fat and restaurant grease
Feed grade vegetable fat	Vegetable oil (canola oil, soybean oil), acidulated vegetable soap stocks and other refinery by-products
Oilseeds (Fats not extracted)	Whole canola seeds - ether frozen or canola screenings used as 'slow release' fat sources. Process through hammer mill or roll to improve utilization of energy

Based on price and fat digestibility, fat source is determined to use in feed (Shannon, 2001). It is well known that UFA from triglycerides has a better digestibility and absorption rate than the SFA (Shannon, 2001). Vegetable oils include a high proportion of the UFA, whereas animal fats contain more SFA. Factors affecting digestibility is the ratio of UFA to SFA (NRC, 1998). Table 4 shows the characteristics of fat sources (fats or oils) used in animal diets. Cera *et al.*

(1988a) observed that utilization of dietary fat by the young pig, particularly during the early postweaning period, is limited due to insufficient fat digestion and absorption. Rodas *et al.* (1995) indicated that animal fats are less digestible than vegetable fats. Limited utilization of animal fat has been attributed to a high content of long-chain, saturated fatty acids that have a restricted entry into the micellar phase (Freeman, 1969).

Table 4. Characteristics of fat sources (as-fed basis) (NRC, 1998)

Sources	**Total saturated**	**Total unsaturated**	**Fatty acids (% of total)**		**Energy ME (kcal/kg)**
			Oleic C18:1	**Linoleic C18:2**	
Choice white grease	40.8	59.2	41.1	11.6	7,955
Poultry fat	31.2	68.8	37.3	19.5	8,180
Restaurant grease	29.9	70.1	47.5	17.5	8,205
Tallow	52.1	47.9	36.0	3.1	7,680
Canola oil	7.4	92.6	56.1	20.3	8,410
Coconut oil	91.9	8.1	5.8	1.8	8,070
Corn oil	13.3	86.7	24.2	59.0	8,755
Soybean oil	15.1	84.9	22.8	51.0	8,400

Palm oil is a vegetable oil which is rich in the SFA and the content of palmitic acid (C16:0) is about 45% of the total fatty acids (Edem, 2002). Extracted corn oil in growing pigs had a better digestibility compared with high-oil corn (Kim *et al.*, 2013). The chain length of a fatty acid is an important determinant of fat digestion and absorption, since different chain of fatty acids have different metabolic routes (Gu *et al.*, 2003). SCFA and MCFA can absorbed much easier than LCFA (Cera *et al.*, 1989).

2.3. Benefits of fat use in pig diet

2.3.1. Effects of fat on growth performance in pigs

Tokach *et al*. (1995) found that the supplementaion of fat had positive effects on body weight and FCR in weaning pigs. This finding is correlated with the results of Baudon *et al*. (2003). Improved growth performance was related with the effects of fat supplementation on decreasing feed passage rate in the gut (Pettigrew and Moser, 1991). Also Pigs supplied diet with added fat had a 10 % increased growth performance (Campbell, 2005). Enser (1984) found that linoleic acid supplementation in pig diet could maintain the growth in pig normally from weaning to finishing stage. Fat supplementation in finishing pigs diet could improve the growth performance (Lopes-Bote *et al*., 1997). Weber *et al*. (2006) found similar findings, suggesting that growth performance and feed efficiency were improved in finishing pigs when fat was added to the diet.

2.3.2. Effects of fat on nutrient digestibility in pigs

Imbeah and Sauer (1991) observed growing-finishing pigs increased the AID for AA with increasing dietary fat level. Li and Sauer (1994) reported that the AID of CP in weaning pigs was increased linearly with increasing fat contents. Kil and Stein (2011) found that addition of soybean oil or choice white grease improved AID of AA in growing pigs. Kil *et al*. (2010) reported that both AID of fat and ATTD of fat increased as dietary level increased. Frobish *et al.* (1970) observed that apparent digestibility of fat increased with an increase in age and with addition of fat to the diet. Desnuelle and Savary (1963) demonstrated that triglycerides containing short chain fatty acids are hydrolyzed faster than triglycerides of long-chain fatty acids. Lloyd and Crampton (1957) also found that, as the molecular weight of the fat source increased, there was a decrease in the digestibility of fat. Stahly (1984) reported that UFA : SFA ratio affected the apparent digestibility of fat (Table 5). The ratio of UFA : SFA in common feedstuffs is various from 0.8 (tallow) to 6.0 (vegetable oils) (Stahly,1984). The ratio of UFA : SFA increased to more than 1.5, and then fat digestibility increased (Stahly, 1984). Cera *et al*. (1988b) demonstrated that vegetable oil was more digestible than tallow, but difference among fat sources was reduced as the pig grew. Frobish *et al*. (1970) observed no differences of fat digestibility were in vegetable oil and corn oil. Lauridsen *et al*. (2007) indicated that blended fat supplementation of animal fat and vegetable oil in pig diets showed negative effect on apparent fat digestibility.

Table 5. Effects of the unsaturated:saturated fatty acid ratio(UFA:SFA) on fat digestibility in pigs (Stahly, 1984)

Carbohydrate source	Fat supplement	UFA:SFA	Range of fat digestibility(%)
Maize	Tallow	1:5	85-92
Barley	Tallow	1:0	70-85
Maize	Soybean oil	4:8	90-95
Barley	Soybean oil	4:0	90-95

Jones *et al*. (1992) reported that fat supplementation in weaning pig diet had greater digestibility of N and GE compared with no fat diet. Asplund *et al*. (1960) found greater digestibility of N with fat supplementation. These observation suggested that there was a longer transit time in digestive track due to improved digestibility of N. Berschauer (1984) showed apparent digestibility of CP in piglets fed fat was higher than control groups. However, this result is opposite with the results of De Rouchey *et al*. (2004). They demonstrated that there are no improvements in apparent nutrient digestibility with fat supplementation. Cho *et al*. (2008) demonstrated that mono-diglycerides could increase ATTD and AID of DM, GE, N and crude fat. Brooks (1967) reported that added soybean oil to growing pig diets increased in digestibility of fat, but other components (protein, fiber and dry matter) were not improved in digestibility. In contrast, Lewis *et al*. (2000) indicated that there were significant increases on ileal digestibility of DM and energy in grower pigs diet with fat supplementation.

2.3.3. Effect of fat on milk fat contents in lactating sows

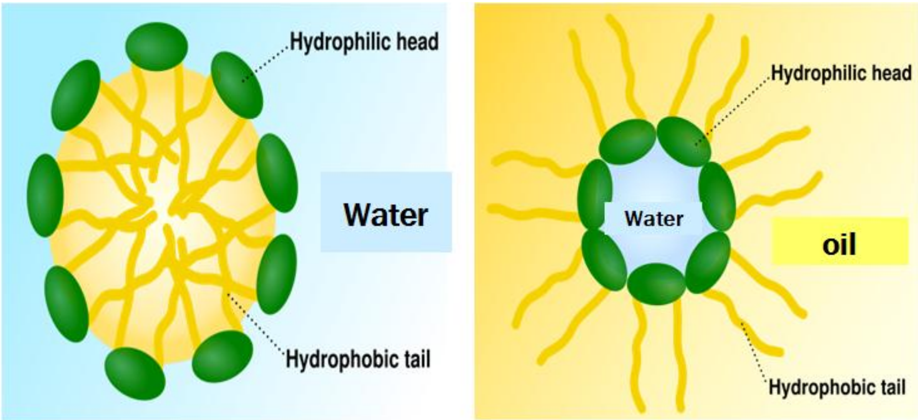
Dietary fat supplementation improved energy supply and fat metabolism of the sow during late gestation and lactation, resulting in increase of the fatty acid level of colostrum and milk and the livability of piglets (Hurley and Bryso, 1999). As the energy provided by lipids is primarily delivered to mammary glands, sows fed with lipid-enhanced feed produce high fat milk during lactation (van den Brand *et al.*, 2000). Jackson *et al.* (1995) determined that dietary fat addition during last 2 weeks of gestation and lactation significantly increased colostrum and milk fat content. Kveragas *et al.* (1988) demonstrated that sows fed fat-containing diets exhibited greater plasma free fatty acids contents during gestation and lactation, which was helpful in improving the lipid content of colostrum. Azain (1993) reported that the survival rate of low-birth weight piglets (<900 g) was significantly increased by feeding triglycerides to sows. In comparison, Parmley *et al.* (1996) observed that feeding a low-energy diet during gestation reduced the synthesis of fatty acids in the subcutaneous fat tissue of sows, increased the rate of lipolysis and decreased the thickness of subcutaneous fat tissue and weight of the sows.

3. Emulsifiers in livestock industry

3.1. Emulsifier

An emulsifier is a substance that stabilizes an emulsion by decreasing the surface tension (Choi, 2014). Structurally, an emulsifier consists of a hydrophilic head and a lipophilic tail. The hydrophilic head is directed to the aqueous phase and the lipophilic tail to the oil phase (Figure 3). There are two types of emulsifiers. One is the hydrophilic emulsifier which is very efficient in oil in water emulsion. The other is a lipophilic emulsifier which is very efficient in water in oil emulsion. Generally, when water and oil will not mix each other, then emulsifier keeps the mixture to be stable and prevents separating into two layers from the mixture.

Emulsifiers are most frequently used as food additives. They are used to support in the food processing to maintain quality and freshness. Since it used as feed additives, several researchers demonstrated its effects on animal. Emulsifier has a significant effect on fat digestibility in pig diet (Jones *et al*., 1992), and Polin (1980) indicated that emulsifier could increase the absorption of tallow in chicken. Also Lee (2016) demonstrated that emulsifier could improve growth performance in pigs.



<Oil-in-water emulsion> **< Water-in-oil emulsion>**

Figure 3. Different type of emulsifiers and their emulsion

Hydrophilic-lipophilic balance (HLB)

Hydrophilic-lipophilic balance (HLB) is a very useful concept for emulsifier category reviewed by Becher (2001). This calculation of an HLB value for each emulsifier is based on the number and relative polarity of functional group in a surface active molecule. The value of HLB for emulsifier is a measure of the degree of hydrophilicity or hydrophobicity and is determined by calculating the values for other regions of the molecule. Other method is developed by Davies in 1957. It is related to oil and water solubility. The value of HLB expresses an actual numerical correlation of the emulsifying and solubilizing characteristics of different emulsifying agent.

Figure 4 shows the value of HLB for emulsifier and its function. High HLB values are related with easy water solubility. High HLB emulsifiers are available for O/W emulsions and Low HLB emulsifiers are available for W/O emulsions. There will be a very effective for solubilization of another ingredient.

Ratio(%)		HLB value
Hydrophilic portion	Lipophilic portion	
0	100	0
10	90	2
20	80	4
30	70	6
40	60	8
50	50	10
60	40	12
70	30	14
80	20	16
90	10	18
100	0	20

Figure 4. The value of HLB for emulsifier and its function (KIMIN Inc.).

3.2. Effects of endogenous emulsifier(bile salts) in pigs

Bile salt is the natural emulsifier that can improve digestibility of fat in feeds (Choi, 2014). Bile salt is the ionized (-COO^-) form of bile acids. Bile acid is the protonated (-COOH) form. Bile acids are the final outcomes of cholesterol utilization, and they are produced from the liver and secreted in the intestine through the gall bladder.

There are two types of bile acids (Figure 5). One is primary bile acids that made by synthesis in the liver which are chenodeoxycholic acid and cholic acid. The others are secondary bile acids that is changed from the primary bile acids through modified by anaerobic bacteria such as lithocholate (from chenodeoxycholate) and deoxycholate (from cholate). They are conjugated via an amide bond at the terminal group with either of the amino acids (van Mil *et al.*, 2004).

The bile salts should be classified as amphipathic compounds (Hartley 1936) and has the important role in the digestion of fat (Knarreborg *et al.*, 2004).

The secretion of bile salts is thought as a major limitation for fat digestion in chicken during the first weeks after birth (Knarreborg *et al.*, 2004). Different bile acids were found by species (Table 6).

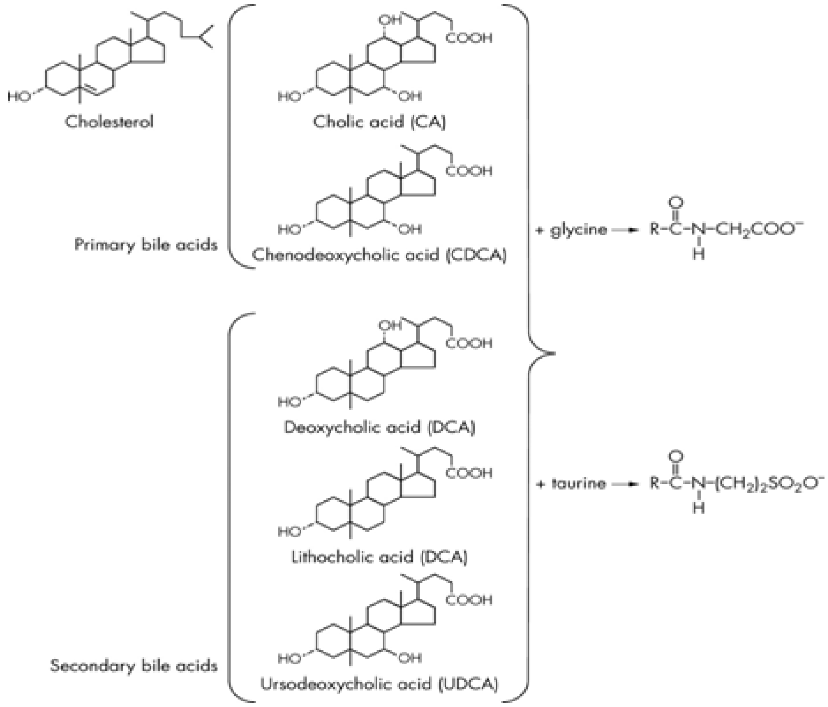


Figure 5. Chemical structure of the major bile acids (van Mil *et al.*, 2004)

Table 6. Bile acids by species (Luis, 2002)

Bile acid	Species
Chenodeoxycholic acid	Bear, Hamster, Human, Pig
Ursodeoxycholic acid	Bear
Deoxycholic acid	Cat, Human, Rabbit
Hyocholic acid	Pig
B-murichilic acid	Mouse, Rat
Cholic acid	Bear, Cat, Hamster, Human, Mouse, Pig, Rabbit, Rat

Bile salt and phospholipid are favorable emulsifiers, which can emulsify fat, form micelles, extend the interface of fat, enhance the action of lipase and promote the digestion and absorption of fat (Jensen *et al.*, 1997). Orban and Harmon (2000) reported that the bile supplementation to weaning pig diets didn't show any negative effect on growth performance and show positive effect on fat digestibility. Reinhart *et al.* (1988) found that bile salt supplementation to weaning pig diets increased growth performance linearly.

3.3. Effects of exogenous emulsifier in pigs

3.3.1. Lecithin

Lecithin (a phospholipid) is a mixture of surface-active agents (Gu and Li, 2003). These phospholipid molecules contain a hydrophobic portion with an affinity for fats and oils and a hydrophilic portion with an affinity for water (Gu and Li, 2003). Lecithin could be found in soybeans, egg yolks, and wheat germ. Lecithin is extracted from soybeans for use. Lecithin is also a main constituent in the lipid bilayers of cell membranes. In lecithin (phospholipid), phosphate head group is very negatively charged (Figure 6). It can dissolve easily in water by forming hydrogen bonds because it is hydrophilic. The long fatty acid tail chains are uncharged. They don't dissolve in water. They are hydrophobic. Soy lecithin from soybean oil provides energy to animals, and it also serves as an emulsifier to improve the fat utilization in animals.

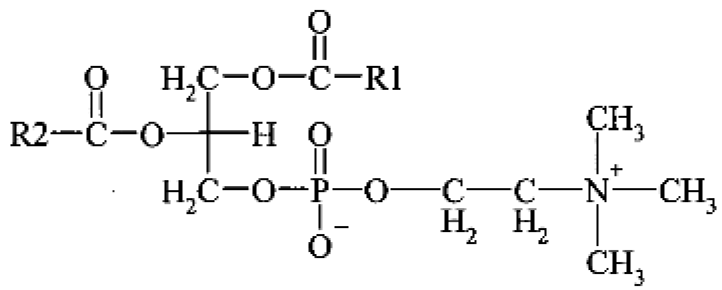


Figure 6. Chemical structure of lecithin (google, 2016)

Jin *et al*. (1998) demonstrated that the lecithin supplementation increased digestibility of GE, DM, EE and CP in piglets. Overland *et al*. (1993) reported that lecithin supplementation to soybean oil diet could increase nitrogen accretion ($P < 0.05$) but not fat digestibility. Another experiment showed that lecithin had no positive action on the utilization of grease originating from slaughterhouse offal (Overland and Sundstol, 1995). Jones *et al*. (1992) observed that lecithin could significantly improve average daily weight and feed intake in 21 day weaned piglets in the first 2 weeks postweaning. Soares *et al.* (2002) found that lecithin improved an apparent digestibility of UFA than that of SFA. Another action of lecithin is to provide choline, which participates in the development of brain, nerve and liver function as the basis of the compound acetylcholine, and to spare carnitine (Zeisel, 2000). Lecithin plays an important role in cell membranes in transferring nutrients and waste substances, adjusting inner pressure of the cell and exchanging ions between the cells (Israel and Ansell, 1988).

While some authors demonstrated a potential benefit of lecithin (Jones *et al*., 1992), others indicated no enhancing effect on digestibility (Overland *et al*., 1993, 1995). This discrepancy is most likely due to differences in fat composition including variations in lecithin content and quality.

3.3.2. Lysolecithin

Soy lysolecithin is a food emulsifier and has been manufactured by pancreatic phospholipase A2 from the lecithin molecule. Joshi *et al*. (2006) found that phospholipids were changed into lysolecithin by removing one of the fatty acids in the phospholipids during the enzymatic conversion (Figure 7).

Lysolecithin increased the growth performance and increased the apparent digestibility of dietary fat in weaning pigs (Rodas, 1995; Danek *et al*., 2005). The feeding of lysolecithin tended to lower ($P<0.1$) serum triglycerides compared with the feeding of the without lysolecithin (Jones *et al.,* 1992; Rodas, 1995). Melegy *et al*. (2010) reported indicated that lysolecithin supplementation could improve the fat digestibility by developing its emulsification with better fat absorption. Averette

(2001) found that dietary lysine can be reduced using lysolecithins and results in enhanced digestibility of various water-soluble nutrients. Xing *et al.* (2004) demonstrated that lysolecithin improve fat digestibility and protein digestibility. Khidir *et al.* (1995) reported that lower concentrations of lysophosphatidyl choline could make the surface membranes permeable. Zhang *et al.* (2011) indicated that both lecithin and lysolecithin activated as an emulsifier in the initial stage of fat digestion and increase the surface area of fat droplets.

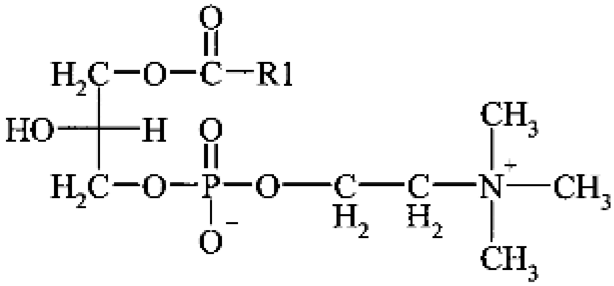


Figure 7. Chemical structure of lysolecithin (lysophosphatidylcholine).

4. Applications of sodium stearoyl lactylate in animal diet

4.1. Characteristics of sodium stearoyl lactylate

Dietary exogenous hydrophilic emulsifier (SOLMAX®50) is composed with sodium stearoyl-2-lactylate (SSL) that is the sodium salt of a long-chained carboxylic acid containing two ester linkages (Figure 8). It is a hydrophilic emulsifier and The value of HLB for SOLMAX®50 is around 20, so it is an O/W type emulsifier (Choi, 2014). The SSL was approved by Food and Drug Administration (FDA) as a food additive and is applied in the food industry as a whipping agent and a conditioning agent. It has a hygroscopic characteristic so it could be lately introduce to feed additive market due to this characteristic. But, SOLMAX®50 was developed to feed additive emulsifier that this issue solved. SSL is an excellent hydrophilic emulsifier for oil in water emulsions but few experimental studies have tested in feed industry.

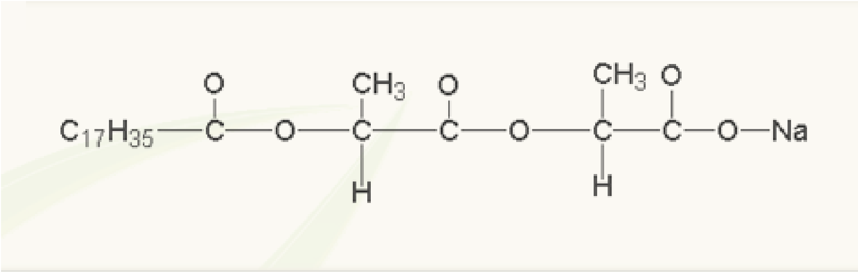


Figure 8. Structure of sodium stearoyl-2-lactylate

4.2 Effects of sodium stearoyl lactylate in livestocks

Kim and Cho (2008, unpublished) reported that SSL supplementation in the growing pig diet of a reduced energy content had positive effect on growth performance. Moon (2012) found that SSL supplementation in the weaning pig diet could improve the fat digestibility. Jeong *et al*. (2009) didn't show the effect of supplementation of the SSL on growth performance in Hanwoo during fattening period but there was an significant improvement on marbling score and meat quality grade. Also Choi (2013) demonstrated that supplementation of the SSL in Hanwoo diet could improve the growth performance and the meat quality. Those are the effects of SSL in ruminant, and studies in swine and broiler are very limited. Choi (2014) found that SSL supplementation in broiler diet with reduced energy levels could improve the growth performance and feed efficiency.

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Chapter III: Effects of Exogenous Hydrophilic Emulsifier Supplementation on Growth Performance, Blood Profiles and Nutrient Digestibility in Weaning Pigs

ABSTRACT: This study was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on growth performance, blood profiles and nutrient digestibility in weaning pigs. A total of 80 weaning pigs ([Yorkshire × Landrace] × Duroc), body weight (BW) = 7.22 ± 0.23 kg; weaned at day 28 ± 3) were randomly allotted to one of four treatments in a randomized complete block (RCB) design in 5 replicates with 4 pigs per pen. Dietary treatments were divided by the supplementation level of emulsifier; 1) Control : corn-SBM based diet (3,265kcal of ME/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier, 4) E0.15 : basal diet + 0.15% emulsifier. The phase I (0-2nd wk after weaning) diet contained 3,265 kcal of ME/kg and 23.70% crude protein and phase II (3rd–5th wk after weaning) diet contained 3,265 kcal of ME/kg and 20.90% crude protein, respectively. Diets were provided *ad libitum* during the whole experimental period. All other nutrients were met or exceeded requirements of NRC (1998). There were no significant differences in BW, ADG, ADFI, and G:F ratio during phase I. However, ADG during the whole experimental period was increased as hydrophilic emulsifier level increased (linear, P=0.01). Also G:F ratio during entire experimental period was increased as hydrophilic emulsifier level increased (linear, P<0.01), and the results of E0.05, E0.10 and E0.15 treatments during phase II were differed significantly compared to those in control diet (P=0.02). There were no significant differences in total cholesterol, triglyceride, LDL and HDL cholesterol concentrations on phase I. However, in phase II, there was a quadratic response (quadratic, P<0.01) in total cholesterol, LDL cholesterol and HDL cholesterol concentrations as hydrophilic emulsifier level increased and the results in E0.10 were reduced compared to those in control, E0.05 and E0.15 regarding total cholesterol (P<0.01), LDL cholesterol

($P<0.01$) and HDL cholesterol concentrations ($P=0.02$). The nutrient digestibilities of dry matter, crude protein and crude ash were not affected by dietary treatments. But there was a quadratic effect on crude fat digestibility as hydrophilic emulsifier level increased (quadratic, $P=0.01$), and the results in E0.05, E0.10 and E0.15 treatment were significant different compared to those in control diet ($P<0.01$). Consequently, these results demonstrated that 0.05% of exogenous hydrophilic emulsifier supplementation in diet contributed positive effects on growth performance, specially G:F ratio and fat digestibility in weaning pigs.

Key words: Exogenous Hydrophilic Emulsifier, Growth Performance, Blood Profiles, Nutrient Digestibility, Weaning Pigs

INTRODUCTION

Weaning typically influenced physiological responses in young pig, particularly intestinal function and secretion (Cera *et al*., 1990). Cera *et al*. (1988) demonstrated that villi height was reduced and morphological changes were marked initially after weaning. Fat supplementation of diets is recognized as a valuable method to provide the sufficient energy in the weaning pigs (Moon, 2012). But, early weaned pigs were less capable of digesting and utilizing dietary fat than older pigs (Pettigrew and Moser, 1991). Weaning piglets secreted bile in very small amounts and have a limited ability for emulsification (Jones *et al*., 1991). When the fat content of piglet diets was high, emulsifier supplementation may improve a fat digestibility (Jones *et al*., 1991; Overland *et al*., 1993; Soares and Lopez-Bote, 2002).

An emulsifier was a substance that stabilizes an emulsion by decreasing the surface tension (Choi, 2014). Structurally, an emulsifier consists of a hydrophilic head and a lipophilic tail. The hydrophilic head is directed to the aqueous phase and the lipophilic tail to the oil phase. So its structural characteristic could help the fat digestion in animal body (Davis, 1994).

Dietary exogenous hydrophilic emulsifier (SOLMAX®50, KIMIN INC., Korea) consisted of sodium stearoyl-2-lactylate (SSL) that had a hydrophilic characteristic which was easily dissolved in water because metabolism of gastrointestinal tract in the body was based on the water. Pigs had an internal emulsifier which was bile salt, but quantity and activity of bile salt were limited in weaning pig. So exogenous hydrophilic emulsifier could help the action of bile salt in weaning pig. However, only a few studies for emulsifier supplementation in weaning pig were conducted, and most researches were concentrated primarily on lecithin which was a lipophilic emulsifier and had inconsistent result on growth performance in weaning pig diet (Frobish *et al*., 1969; Kanyo *et al*., 1985; Van Wormer and Pollman, 1985; Jones *et al*., 1990a,b).

The aim of the present experiment was to investigate the effects of exogenous hydrophilic emulsifier supplementation on growth performance, blood profiles and nutrient digestibility in weaning pigs.

MATERIALS AND METHODS

Experimental design and diets

A total of 80 weaning pigs[(Yorkshire × Landrace) × Duroc] with average 7.22 ± 0.23 kg initial body weight weaned at day 28 ± 3 were used in a 5- wk feeding trial, at a research farm located in Suwon, South Korea. Weaning pig were allotted to one of four treatments in 5 replicates with 4 pigs per pen in a randomized complete block (RCB) design by BW and sex. Dietary treatments were divided by the dietary level of emulsifier; 1) Control : corn-SBM based diet (3,265kcal of ME/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier, 4) E0.15 : basal diet + 0.15% emulsifier. Experiment was conducted with corn - soybean meal - based diet and two phase feeding program was used.

The phase I (0-2nd wk after weaning) diet contained 3,265 kcal of ME/kg and 23.70% crude protein and phase II (3rd–5th wk after weaning) diet contained 3,265 kcal of ME/kg and 20.90% crude protein, respectively. Emulsifier (SOLMAX®50, KIMIN INC., Korea) in dry form was supplemented in basal diet according to designated treatments. All nutrients of experimental diets were met or exceeded the nutrient requirement of NRC (1998). Formula and chemical composition of experimental diet were presented in Table 1 and 2.

Animal management and measurement

Pigs were housed in a concrete-slatted floor (1.90 × 2.15 m), equipped with a feeder and a nipple drinker to allow freely access to feed and water during the whole experimental period. The ambient temperature in the weaning house was kept 31℃ during the first 7 days and lowered 1℃ every week to 27℃. Body weight and feed consumption were recorded at 0, 2nd and 5th wk to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F ratio).

Blood sampling

Blood samples were taken from anterior vena cava of 5 pigs per treatment for measuring total cholesterol, triglyceride, LDL (low density lipoprotein) cholesterol and HDL (high density lipoprotein) cholesterol when the body weight at 0, 2nd and 5th wk were recorded. Collected blood samples were quickly centrifuged for 15 min at 3,000 rpm on 4℃ (Eppendorf centrifuge 5810R, Germany). The serum was carefully transferred to 1.5 ml micro tubes and stored at -20℃ until analysis. Blood sample was analyzed using a blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co.).

Digestibility trial

For evaluating total tract digestibility, a total of 20 weaning pigs ([Yorkshire × Landrace] × Duroc; 12.08 ± 1.51 kg of average BW) were allotted one of four treatments with completely randomized design (CRD). All pigs were housed in a metabolic crate in a room of steady temperature (27 ºC). The experimental diets were provided twice a day at 07:00 and 19:00 h by same amount with 1% of body weight. After a 5 days adaptation period, 0.5% of chromium oxide was manually mixed into the first meal on d 6 as an initial marker. On d 11, 0.5% ferric oxide was used as a finish marker. Feces and urine collections were initiated when the chromium oxide appeared in the feces and continued until the next appearance of ferric oxide in the feces. Excreta and urine were collected daily at 19:00 h and stored -20 ºC until analysis. Collected excreta were pooled, sealed in plastic bags, dried in an air-forced drying oven at 60℃ for 72 h, and ground into 1 mm particles in a Wiley mill for analysis of moisture, crude protein, crude fat and crude ash contents. Urine was collected daily in a plastic container containing 50 ml of 0.1N H_2SO_4 and frozen during the 5 day collection period for nitrogen retention analysis. Analysis of the experimental diets, excreta and urine was conducted according to the methods of the AOAC (1995).

Statistical analysis

The experimental data were carried out by least squares mean comparisons and evaluated using PDIFF option in General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). The pen of pigs was used as the experimental unit in growth performance, and individual piglet was used as the experimental unit in digestibility trial and blood profiles. Differences were declared significant at $P<0.05$. Also pre-planned orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of emulsifier except control diet.

RESULTS AND DISCUSSION

Growth performance

There were no significant differences in BW, ADG, ADFI, and G:F ratio during phase I (Table 3). However, ADG during whole experimental period was increased as hydrophilic emulsifier level increased (linear, $P=0.01$). Also G:F ratio during entire experimental period was increased as hydrophilic emulsifier level increased (linear, $P<0.01$), and the results of E0.05, E0.10 and E0.15 treatments during phase II were differed significantly compared to those in control diet ($P=0.02$).

Xing *et al.* (2004) reported that growth performance was improved by 0.1% lysolecithin supplementation to diets with added lard in weaning pigs. Jones *et al.* (1992) observed that emulsifier significantly improved average daily gain and feed intake in d 21 weaned piglets in the first 2 weeks postweaning. Rodas *et al.* (1995) found that addition of emulsifier to young pig diets containing 4% lard and 4% soy oil as the fat source improved the growth performance. Van Wormer and Pollman (1985) demonstrated that low level of emulsifier showed a similar performance with 4% choice white grease in young pigs. Those observations were in agreement with the present study. Hydrophilic emulsifier supplementation in weaning pig diet improved the emulsification process during fat digestion (Augur *et al*., 1947) so it made the improvement of growth performance in weaning pigs.

But there were the conflicting reports against results of the present study. Overland *et al*. (1993) indicated no improvement of growth performance by addition of emulsifier to young pig diets. Also, Kanyo *et al*. (1985) reported that emulsifier supplementation to weaning pig diets didn't show the effect on growth performance. Jones *et al*., (1990b) reported that emulsifier supplementation in weaning pig diet had no effect on growth performance. Holzgraefe *et al*. (1986) observed that growth performance was not improved by supplementation of emulsifier to weaning pig diet. Those results were due to limited digestion ability in young animals. The utilization of dietary fat was limited due to immaturity of intestinal growth in weaned pigs (Cera *et al.,* 1988). Specially, weaning pigs could not use added dietary fat efficiently in early weaning phase (Tokach *et al*., 1995). The present result also didn't show the emulsifier effect in phase I even though there was a tendency to improve BW at 5th wk (P=0.09) and ADG during whole periods (P=0.07). Also G:F ratio showed a significant difference in phase II (P<0.01) and whole period (P<0.01). Therefore, it demonstrated that pigs fed emulsifier could increase the growth performance by improving fat utilization efficiency in the body.

Blood profiles

In table 4, there were no significant differences in total cholesterol, triglyceride, LDL and HDL cholesterol concentrations on phase I. However, in phase II, there was a quadratic response (quadratic, P<0.01) in total cholesterol, LDL cholesterol and HDL cholesterol concentrations as hydrophilic emulsifier level increased and the results in E0.10 were reduced compared to those in control, E0.05

and E0.15 regarding total cholesterol concentration (P<0.01), LDL cholesterol concentration (P<0.01) and HDL cholesterol concentrations (P=0.02).

This finding was in agreement with the results of Todorova *et al*. (2011) who also found that emulsifier in weaning pig diet reduced the serum cholesterol. The feeding of lysolecithin tended to lower serum triglycerides compared with the feeding without lysolecithin (Rodas *et al*., 1995) due to rapid metabolism of fat in blood. According to the results of Jones *et al*. (1992), rapid rates of absorption and metabolism of ingested fat made lower serum triglycerides concentrations when emulsifier supplemented. They found that pigs fed tallow with emulsifier had lower serum triglycerides concentrations. Although mode of action on this was unclear, they suggested that fat digestibility increased and serum triglycerides concentrations decreased when pigs fed emulsifier, resulting chylomicrons were disappeared from the blood with a quick rate and secreted into a blood at a slower rate. Therefore, emulsifier supplementation in weaning pig diet could decrease cholesterol level by rapid metabolism.

Nutrient digestibility

As shown in Table 5, the nutrient digestibilities of dry matter, crude protein and crude ash were not affected by dietary treatments. But there was a quadratic effect on crude fat digestibility as hydrophilic emulsifier level increased (quadratic, P=0.01), and the results in E0.05, E0.10 and E0.15 treatment were significant different compared to those in control diet (P<0.01).

This result was in agreement with Soars *et al*. (2002) who reported that lecithin improved the apparent digestibility of fat. Jones *et al.* (1992) also reported that emulsifiers increased the fat digestibility in the young pigs. In addition, lysolecithin improved the apparent digestibility of dietary fat in weaning pigs (Danek *et al*., 2005). Considering the present result and previous studies, supplementation of emulsifier improved the fat digestibility in weaning pigs.

CONCLUSION

This experiment demonstrated that hydrophilic emulsifier supplementation in weaning pig diets improved growth performance, specially G:F ratio. Also hydrophilic emulsifier supplementation reduced total cholesterol concentrations and LDL cholesterol concentrations in blood, and it could improve crude fat digestibility in weaning pigs. Consequently, these results suggested that exogenous hydrophilic emulsifier supplementation in diet had positive effects on growth performance and fat digestibility in weaning pigs..

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Table 1. The formulas and chemical composition of experimental diet (0-2week)

Item	Treatment[1)]			
	Control	E 0.05	E 0.10	E 0.15
Ingredients, %				
EP Corn	27.67	14.09	14.24	14.38
SBM-44	34.67	34.30	34.32	34.34
Barley	11.89	18.00	18.00	18.00
Sugar beet pulp	0.00	5.78	5.56	5.35
HP300[2)]	7.88	7.88	7.88	7.88
Whey powder	3.00	3.00	3.00	3.00
Lactose	12.00	12.00	12.00	12.00
Soybean oil	0.00	2.00	2.00	2.00
MCP	1.12	1.19	1.19	1.19
Limestone	1.00	0.95	0.95	0.95
L-Lysine HCl	0.10	0.09	0.09	0.09
DL-Methionine	0.03	0.03	0.03	0.03
Vit. mix[3)]	0.12	0.12	0.12	0.12
Min. mix[4)]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl(25%)	0.10	0.10	0.10	0.10
Zinc oxide	0.10	0.10	0.10	0.10
Emulsifier[5)]	0.00	0.05	0.10	0.15
Total	100.00	100.00	100.00	100.00
Chemical composition [6)]				
ME, kcal/kg	3,265.02	3,265.00	3,265.06	3,265.05
Crude protein, %	23.70	23.70	23.70	23.70
Total lysine, %	1.35	1.35	1.35	1.35
Total methionine, %	0.35	0.35	0.35	0.35
Calcium, %	0.80	0.80	0.80	0.80
Total phosphorus, %	0.65	0.65	0.65	0.65

1) Control: corn-SBM based diet (ME 3,265 kcal/kg), E 0.05 : basal diet + emulsifier 0.05% (SOLMAX®50, KIMIN INC., Korea), E 0.10: basal diet + emulsifier 0.10%, E0.15 : basal diet + emulsifier 0.15%.

2) HP300 (Hamlet protein, Horsens, Denmark)

3) Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4 mg

4) Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

5) SOLMAX®50, KIMIN INC., Korea .

6) Calculated value

Table 2. The formulas and chemical composition of experimental diet (3-5 week)

Item	Treatment[1)]			
	Control	E 0.05	E 0.10	E 0.15
Ingredients, %				
EP Corn	47.87	33.25	33.53	33.81
SBM-44	28.33	27.84	27.86	27.90
Barley	8.90	17.64	17.29	16.92
Sugar beet pulp	0.00	4.33	4.33	4.33
HP300[2)]	6.00	6.00	6.00	6.00
Whey powder	2.50	2.50	2.50	2.50
Lactose	4.00	4.00	4.00	4.00
Soybean oil	0.00	2.00	2.00	2.00
MCP	0.98	1.01	1.01	1.01
Limestone	0.78	0.75	0.75	0.75
L-lysine HCl	0.10	0.09	0.09	0.09
DL-methionine	0.00	0.00	0.00	0.00
Vit. mix[3)]	0.12	0.12	0.12	0.12
Min. mix[4)]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl(25%)	0.10	0.10	0.10	0.10
Emulsifier[5)]	0.00	0.05	0.10	0.15
Total	100.00	100.00	100.00	100.00
Chemical composition [6)]				
ME, kcal/kg	3,265.02	3,265.05	3,265.00	3,265.03
Crude protein, %	20.90	20.90	20.90	20.90
Total lysine, %	1.15	1.15	1.15	1.15
Total methionine, %	0.30	0.30	0.30	0.30
Calcium, %	0.70	0.70	0.70	0.70
Total phosphorus, %	0.60	0.60	0.60	0.60

1) Control: corn-SBM based diet (ME 3,265 kcal/kg), E 0.05 : basal diet + emulsifier 0.05% (SOLMAX®50, KIMIN INC., Korea), E 0.10: basal diet + emulsifier 0.10%, E0.15 : basal diet + emulsifier 0.15%.

2) HP300 (Hamlet protein, Horsens, Denmark)

3) Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4 mg

4) Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

5) SOLMAX®50, KIMIN INC., Korea .

6) Calculated value

Table 3. Effects of hydrophilic emulsifier supplementation on growth performance in weaning pigs

Item	Treatments[1]				SEM[2]	P-value[3]		
	Control	E 0.05	E 0.10	E 0.15		Treatment	Linear	Quadratic
Body weight, kg								
Initial	7.18	7.21	7.16	7.20	0.229	0.60	0.67	0.22
2 week	8.94	9.92	9.91	9.84	0.289	0.13	0.85	0.93
5 week	18.98	21.16	21.63	21.00	0.499	0.08	0.86	0.52
ADG, g								
0-2 week	125	194	197	189	11.1	0.12	0.90	0.89
3-5 week	478	535	558	531	12.9	0.09	0.84	0.38
0-5 week	337	398	413	394	11.4	0.10	0.01	0.57
ADFI, g								
0-2 week	288	332	336	330	8.2	0.14	0.92	0.78
3-5 week	858	880	902	840	19.2	0.60	0.42	0.33
0-5 week	632	662	674	636	13.9	0.31	0.48	0.68
G:F ratio								
0-2 week	0.43	0.58	0.58	0.57	0.026	0.11	0.84	0.88
3-5 week	0.56^{B}	0.60^{A}	0.62^{A}	0.63^{A}	0.010	0.02	0.27	0.86
0-5 week	0.53	0.60	0.61	0.62	0.011	0.07	<0.01	0.46

[1] Control: corn-SBM basal diet(ME 3,265 kcal/kg, no oil), E 0.05: basal diet(ME 3,265 kcal/kg, soy oil 2%)+ emulsifier 0.05%, E 0.10: basal diet(ME 3,265 kcal/kg, soy oil 2%)+emulsifier 0.10%, E 0.15: basal diet(ME 3,265kcal/kg, soy oil 2%)+emulsifier 0.15%.

[2] Standard error of mean

[3] Pre-planned orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of emulsifier except control diet.

[AB] Mean with different superscripts in the same row significantly differ (P=0.02).

Table 4. Effects of hydrophilic emulsifier supplementation on blood profiles in weaning pigs

Item	Treatments[1)]				SEM[2)]	P-value[3)]		
	Control	E 0.05	E 0.10	E 0.15		Treatment	Linear	Quadratic
Phase I (2 week)								
Total cholesterol, mg/dL	58.75	65.25	63.75	62.00	3.055	0.94	0.90	0.94
Triglyceride, mg/dL	37.75	34.00	39.75	43.75	3.194	0.94	0.63	0.78
LDL cholesterol, mg/dL	27.00	31.25	31.50	31.00	1.782	0.81	0.97	0.98
HDL cholesterol, mg/dL	28.25	31.00	29.75	28.25	1.690	0.98	0.85	0.91
Phase Ⅱ(5 week)								
Total cholesterol, mg/dL	72.50^{A}	82.00^{A}	57.75^{B}	74.75^{A}	2.938	<0.01	0.19	<0.01
Triglyceride, mg/dL	40.25	48.75	34.75	49.00	2.891	0.24	0.97	0.05
LDL cholesterol, mg/dL	40.25^{A}	39.00^{A}	27.75^{B}	39.00^{A}	1.630	<0.01	1.00	<0.01
HDL cholesterol, mg/dL	28.25^{BC}	35.25^{A}	27.25^{C}	34.00^{AB}	1.249	0.02	0.64	<0.01

[1)] Control: corn-SBM basal diet(ME 3,265 kcal/kg, no oil), E 0.05: basal diet(ME 3,265 kcal/kg, soy oil 2%)+ emulsifier 0.05%, E 0.10: basal diet(ME 3,265 kcal/kg, soy oil 2%)+emulsifier 0.10%, E 0.15: basal diet(ME 3,265kcal/kg, soy oil 2%)+emulsifier 0.15%.

[2)] Standard error of mean.

[3)] Pre-planned orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of emulsifier except control diet.

[AB] Mean with different superscripts in the same row significantly differ (P<0.05)

Table 5. Effects of hydrophilic emulsifier supplementation on nutrient digestibility in weaning pigs

Item	Treatments[1)]				SEM[2)]	P-value[3)]		
	Control	E 0.05	E 0.10	E 0.15		Treatment	Linear	Quadratic
Nutrient digestibility (%)								
Dry matter	92.92	91.00	91.61	90.60	0.348	0.10	0.64	0.28
Crude protein	91.41	89.74	90.60	89.99	0.349	0.41	0.81	0.41
Crude ash	71.29	59.01	65.43	60.54	2.034	0.12	0.79	0.27
Crude fat	38.21[B]	87.54[A]	78.94[A]	85.76[A]	5.345	<0.01	0.54	0.01

[1)] Control: corn-SBM basal diet(ME 3,265 kcal/kg, no oil), E 0.05: basal diet(ME 3,265 kcal/kg, soy oil 2%)+ emulsifier 0.05%, E 0.10: basal diet(ME 3,265 kcal/kg, soy oil 2%)+emulsifier 0.10%, E 0.15: basal diet(ME 3,265kcal/kg, soy oil 2%)+emulsifier 0.15%.

[2)] Standard error of mean

[3)] Pre-planned orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of emulsifier except control diet.

[AB] Mean with different superscripts in the same row significantly differ (P<0.01).

Chapter IV : Effects of Exogenous Hydrophilic Emulsifier Supplementation on Reproductive Performance, Litter Performance and Blood Profiles in Lactating Sows

ABSTRACT: This experiment was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on reproductive performance, litter performance and blood profiles in lactating sows. A total of 40 multiparous sows (F1, Yorkshire x Landrace; Darby, Korea) with an initial BW of 248.6 ± 19.71 kg were allotted to one of four treatments with a 2 x 2 factorial arrangement. The first factor was energy level in diet (3,200 or 3,265 kcal of ME/kg), and the second factor was inclusion of emulsifier (SOLMAX®50, KIMIN INC., Korea). The experimental diets containing different energy levels and with or without supplementation of 0.05% emulsifier was supplied in lactation. All other nutrients were met or exceeded the requirements of NRC (1998), and sows were fed experimental diets *ad libitum* with a free access to waterer during lactating period after 5 days postpartum. During the whole experimental period, there were no significant differences in BW, body weight change (0-21d), backfat thickness, backfat change (0-21d), feed intake and WEI in lactating sows. Although litter weight and litter weight gain were not affected by supplementation of emulsifier, reproductive performance and litter growth tended to have an interaction between energy and emulsifier in piglet weight gain during lactation period (ME x E interaction, P=0.10). In blood profiles, glucose, insulin, total protein and creatinine level in sows were not affected by dietary treatments. But there was tendency for an interaction between energy and emulsifier on PUN concentration of lactating sows (ME x E interaction, P=0.06). Also there was a significant interaction between energy and emulsifier on albumin concentration of sows (ME x E interaction, P=0.02). There were no effects on total cholesterol, triglyceride, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol and free fatty acid level by dietary treatments in lactating sows. But concentration of triglyceride and VLDL-cholesterol at 21 d of lactation was decreased when sows were fed diet containing 3,200 kcal of ME/kg (Energy, P=0.06, P=0.05, respectively). The results of blood profiles in piglet at 21d of lactation were not affected by dietary treatments. Moreover, total cholesterol, triglyceride, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol and free fatty acid concentration in piglet were not affected by dietary treatments. The colostrum and milk compositions such as milk fat, casein, protein, lactose, total solid and solids-not-fat were not affected by dietary treatments. Consequently, these results demonstrated that 0.05% of exogenous hydrophilic emulsifier supplementation in low energy diet (3,200 kcal of ME/kg) had positive effects on litter performance, particularly piglet weight gain in lactating sows.

Key words : Litter performance, Blood profiles, Emulsifier, Lactating sows

INTRODUCTION

The nutritional requirements of the modern lactating sow have increased continuously because of genetic improvements for litter size (Boyd and Kensinger, 1998). During lactation period, sows may have negative energy and nutrient balance because lactating feed intake is insufficient to their nutrients requirement for milk production (Mullan and Williams, 1989; Yang *et al*., 1989). The demand for nutrients during lactation caused metabolic challenges to sows, when sows exposed to heat stress, or nutrient intake was limited (Messias de Branganca *et al*., 1998). Insufficient consumption of nutrients will lead to tissue mobilization from the body for milk production because lactation was a first priority to sow (Pettigrew and Moser, 1991). Therefore fat supplementation to lactating sow diets was very important to minimize body fat loss during lactation period (Pettigrew and Moser, 1991). Energy supply to lactating sow diets is associated with milk production, litter performance and subsequent performance of pigs during nursery and growing – finishing period (Quiniou *et al*., 2008).

An emulsifier was a substance that stabilizes an emulsion by decreasing the surface tension (Choi, 2014). Its structural characteristic could help the fat digestion in animal body (Davis, 1994). When fat content of swine diets was high, exogenous emulsifier supplementation could improve its utilization (Jones *et al*., 1992; Overland *et al*., 1993). Specially, it could improve fat digestibility (Jones *et al*., 1992) and protein digestibility (Dierick and Decuypere, 2004).

Dietary exogenous hydrophilic emulsifier (SOLMAX®50, KIMIN INC., Korea) consisted of sodium stearoyl-2-lactylate (SSL) that had a hydrophilic characteristic which was easily dissolved in water because metabolism of gastrointestinal tract in the body was based on the water.

For a long time, most of studies were tested in weaning or growing-finishing pig diet and only few experiments were conducted in sow diet. Fat supplementation in lactating sow decreased bodyweight loss and backfat loss after lactation (Chilliard, 1993) and increased number of piglet and weight at weaning pig (Reese *et al.*, 1982a,b). Therefore, this research was conducted to demonstrate the effects of exogenous hydrophilic emulsifier supplementation on body condition, reproductive performance, litter performance, blood profiles and milk composition in lactating sows.

MATERIALS AND METHODS

Experimental design and diets

A total of 40 multiparous sows (F1, Yorkshire x Landrace, average 6 parity; Darby, Korea) with an initial BW of 248.6 ± 19.71 kg were used for a trial, at a research farm located in Eum-seong, Korea. The experiment was designed as a 2 x 2 factorial arrangement and main factors were dietary energy level and inclusion of emulsifier. Sows were allotted to each treatment based on body weight and backfat thickness and litter birth weight of lactating sows by completely randomized design (CRD).

The experimental diets contained different energy levels (3,200 or 3,265 kcal of ME/kg) and emulsifier supplementation levels (0 or 0.05%) in lactation period. Dietary treatments were as follows; 1) low energy basal diet : corn-SBM based diet (ME 3,200 kcal/kg), 2) low energy basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) high energy basal diet : corn-SBM based diet (ME 3,265 kcal/kg), 4) high energy basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea). All nutrients were met or exceeded the requirements of NRC (1998). Formulas and chemical composition of experimental diets in lactation periods was presented in Table 1.

Animal management and measurement

Lactating sows were fed experimental lactation diet from the 24 hrs postpartum to 21 d lactation. Also lactating sows were fed experimental diets restrictively during 5 days postpartum (increase of 1 kg/d) then lactating sows were fed diet *ad libitum.* Within 24 hrs postpartum, ear notching and cross-fostering within treatments were done to minimize any affect of initial litter size potentially affecting litter growth. After 3 days of partum, Fe-dextran (150ppm) injection, cutting tail was done. During lactation period, the room temperature and air condition of farrowing barn were kept automatically at 27±2℃ by heating lamps and ventilation fans and air-conditioner in farrowing barn. After weaning, sows were moved to breeding barn.

Physiological change of lactating sows and litter performance

The body weight (BW), backfat thickness (P_2 position) and their feed intake of multiparous sows were measured at 24 hrs postpartum and d 21 of lactation. The weaning to estrus interval (WEI) of sows was recorded from weaning to estrus. After cross-fostering, litter size, litter weight, piglet weight, and their weight gain were measured at 24 hrs postpartum and d 21 of lactation.

Blood Profiles

The blood samples of lactating sows and piglets were collected in EDTA and serum tubes during lactation period (24 hrs postpartum and 21 d lactation). Individual sample was centrifuged at 3,000 rpm on 4 °C for 15 min, and then plasma was separated from blood samples and kept at -20 °C until analysis. The concentration of glucose, insulin, total protein, plasma urea nitrogen, albumin and creatinine were analyzed. Also total cholesterol, triglyceride, HDL - cholesterol, LDL – cholesterol, VLDL – cholesterol and free fatty acid were analyzed.

Colostrum and milk composition

Colostrum (24 h postpartum) and milk of sows at 21 d postpartum were collected from the first and second teats after 0.5ml oxytocin injection into ear vein and collected milk samples were stored at -20 °C until analysis. Casein, fat, protein, lactose, total solid and solid not fat were analyzed using Milkoscan FT 20 (FOSS Electric Co., Denmark).

Statistical Analysis

All of collected data were carried out by least squares mean comparisons and were evaluated using PDIFF option with the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Individual sows and their litters were used as the experimental unit and were analyzed as a 2 x 2 factorial arrangement, and differences were declared significant at $P<0.05$, tendency at $0.05<P<0.10$.

RESULTS AND DISCUSSION

Body weight, backfat thickness, feed intake and WEI in lactating sows

As presented in Table 2, during the whole experimental period, there were no significant differences in body weight, backfat thickness, body weight change and backfat change as well as feed intake and WEI.

These findings were supported by the previous results of Rosero *et al.* (2015) and Lee (2016). Increased fat concentration and energy values in lactating sow diets didn't show any differences on BW at d 21 of lactation and BW change during lactation period (Rosero *et al.*, 2015). Also fat and emulsifier supplementation in lactating sow diet didn't affect BW, BW change and feed intake during lactation period (Lee, 2016). Babinszky *et al.* (1992) found no differences in backfat thickness at weaning for sows fed diets containing either 7.5 or 12.5% fat compared to control sows. Shurson and Irvin (1992) reported that slight reductions in feed intake of sows fed high-fat diets during lactation. Chilliard (1993) found that fat supplementation in lactating sow decreased body weight loss and backfat loss and WEI. Cox *et al.* (1983) observed a decrease in the WEI in sows fed diets containing 10% added fat during summer season. Baidoo *et al.* (1992) found that the inadequate feed intake during lactation period increased the WEI. However, there was no difference in WEI of sows fed different energy of feed. (Reese *et al.*, 1982a).

In present study, because there were no significant differences in body weight, backfat thickness, body weight change and backfat thickness change, emulsifier supplementation did not affect the changes of body weight and thickness, feed intake and WEI of lactating sows. This finding indicated that exogenous hydrophilic emulsifier supplementation in lactating sow diet had no effect on body condition, feed intake and WEI.

Litter performance

The effects of exogenous hydrophilic emulsifier supplementation on reproductive performance and litter performance in lactating sows were shown in Table 3. In the results of litter performance during lactation period, although litter weight and litter weight gain were not affected by supplementation of emulsifier, reproductive performance and litter growth tended to have an interaction between energy and emulsifier in piglet weight gain during lactation period (ME x E interaction, P=0.10). When sows were fed the basal diet containing 3,265 kcal of ME/kg with 0.05% emulsifier showed no difference in piglet weight gain, but when sows were fed diet containing 3,200 kcal of ME/kg with 0.05% emulsifier showed increase in piglet weight gain.

The addition of fat in the lactation diet was generally associated with a higher percentage of solids and fat in milk and a tendency for increased litter weight gain (Pettigrew, 1981; Coffey *et al.*, 1982; Lellis and Speer, 1983). Also fat supplementation in lactating sow increased number of piglet and weaning weight (Reese *et al.*, 1982a,b; Shurson *et al.*, 1986).

In present study, even though litter weight and litter weight gain were not affected by supplementation of emulsifier, there was tendency for an interaction between energy and emulsifier in piglet weight gain during lactation period (ME x E interaction, P=0.10). One possible reason might be that feed intake of lactating sow could affect to different quantity of milk production and when sows were fed diet containing 3,200 kcal of ME/kg with 0.05% emulsifier ate more milk from the sow and then showed increase of piglet weight gain. Another reason might be that emulsifier supplementation in low energy diet increased the fat digestibility, so improved fat digestibility caused to increase of piglet weight gain. Several reports demonstrated that emulsifier affect fat digestibility in piglet diet (Jones *et al*., 1992; Overland *et al*., 1993; Rodas *et al*., 1995; Xing *et al*., 2004)

Consequently, this result demonstrated that exogenous hydrophilic emulsifier supplementation in lactating sow diet had positive effects on piglet weight gain when energy level was 3,200kcal/kg of ME.

Blood Profiles

The effects of exogenous hydrophilic emulsifier supplementation on concentrations of glucose, insulin, total protein, plasma urea nitrogen (PUN), albumin and creatinine in lactating sows and piglets were presented in Table 4.1 and Table 5.1. Also blood concentration of total cholesterol, triglyceride, HDL-cholesterol, LDL–cholesterol, VLDL–cholesterol and free fatty acid in lactating sows and piglets were shown in Table 4.2 and Table 5.2.

In the results of blood profiles in lactating sows, concentrations of glucose, insulin, total protein and creatinine in lactating sows were not affected by dietary treatments. But there was tendency for an interaction between energy and emulsifier on PUN concentration of lactating sows (ME x E interaction, P=0.06). When lactating sows were fed the basal diet containing 3,265 kcal of ME/kg with 0.05% emulsifier, PUN concentration of lactating sows was not affected, but when lactating sows were fed diet containing 3,200 kcal of ME/kg with 0.05% emulsifier, PUN concentration was increased. Also there was a significant interaction between energy and emulsifier on albumin concentration of sows (ME x E interaction, P=0.02). When sows were fed diet containing 3,265 kcal of ME/kg with 0.05% emulsifier showed decreased albumin, but when sows were fed diet containing 3,200 kcal of ME/kg with 0.05% emulsifier showed increased albumin concentration of lactating sows.

Van den Brand *et al*. (2000) demonstrated that feeding a fat-rich diet in sow resulted in a lower plasma insulin concentration during lactation compared with a starch-rich diet. Tilton *et al*. (1999) reported that sows fed 10% tallow diet during lactation period had lower concentrations of PUN than sows fed no oil diet. The reason why concentrations of PUN reduced was that the tallow diet contained more energy and slightly less protein than the control diet, so the change in PUN would be expected. The reduction in PUN in lactating sows fed tallow may result in a decreased rate of amino acid catabolism for use as energy by lactating sows.

There were no significant effects on total cholesterol, triglyceride, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol and free fatty acid level by dietary treatments in lactating sows. But concentration of triglyceride and VLDL-cholesterol at 21 d of lactation was decreased when sows were fed diet containing 3,200 kcal of ME/kg (Energy, P=0.06, P=0.05, respectively).

In the results of blood profiles in piglet at 21 d of lactation, concentrations of glucose, PUN, total protein, albumin and creatinine were not affected by dietary treatments. But the concentrations of total cholesterol, HDL-cholesterol, and LDL-cholesterol in piglet at 21 d of lactation were decreased significantly when sows were fed diet containing 3,200 kcal of ME/kg (Energy, P=0.03, P=0.04, P=0.06). These results were in agreement with the result of blood profiles in lactation sows.

Also the concentrations of triglyceride and VLDL-cholesterol in piglet were did not show significant effect, but emulsifier treatment group showed less concentration of triglyceride and VLDL-cholesterol compared to without emulsifier treatment group (Emulsifier, P=0.12, P=0.11). These results were in agreement with Todorova *et al.* (2011) who found that emulsifier in weaning pig diet reduced the serum cholesterol. The supplementation of emulsifier tended to lower serum triglycerides (P<0.10) compared with the feeding without emulsifier (Rodas *et al.*, 1995). According to Jones *et al.* (1992), lower serum triglycerides with emulsifier supplementation was due to faster rates of absorption of ingested fat. They found that pigs fed tallow with emulsifier had lower serum triglycerides. Mode of action on this was unclear, but they suggested that fat digestibility increased and serum triglycerides decreased when pigs fed emulsifier, resulting chylomicrons were disappeared from the blood with a quick rate and secreted into a blood at a slower rate. Therefore, supplementation of emulsifier affect positively blood components related with fat metabolism.

Colostrum and milk composition

The composition of colostrum and milk in lactating sows including milk fat, protein, total solid and solids-not-fat were not significantly affected by dietary treatments (Table 6).

Supplementing of fat in lactation diet, increased total lipids in colostrum (Coffey *et al*., 1982; Heo *et al*., 2008) and increased colostrum lactose content (Heo *et al*., 2008). Pettigrew (1981) found that an addition of fat in lactating sow diet increased fat contents in colostrum and milk. Also, Rosero *et al.* (2015) demonstrated that fat supplementation to lactation diets increased milk fat content by approximately 13%. Improvement in milk fat content had positive influence on nursing piglet because of the greater amount of energy provided by milk. Also these improved high fat contents in colostrums and milk could result in an improved rate of survival of piglet (Moser, 1983) and composition of dietary fatty acid could bring in a survival of newly born piglets (Azain, 1993). Differ from previous studies, the results of present study did not show any effect on milk composition. It demonstrated that exogenous hydrophilic emulsifier supplementation in lactating sow diet had no significant effect on milk composition.

CONCLUSION

Consequently, the present study demonstrated that exogenous hydrophilic emulsifier supplementation in lactating sow diet did not show effects on performance in sow body condition and suggested that 0.05% of exogenous hydrophilic emulsifier supplementation in low energy diet (3,200 kcal of ME/kg) had positive effects on reproductive litter performance, particularly piglet weight gain in lactating sows.

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Table 1. The formulas and chemical composition of lactation diet

Item[1)] ME, kcal/kg	3,200		3,265	
Emulsifier, %	0	0.05	0	0.05
Ingredients, %				
Corn	63.67	63.74	64.08	64.16
Soybean meal	24.02	24.06	24.67	24.70
Wheat bran	7.01	6.85	4.92	4.76
Tallow	1.40	1.40	2.40	2.40
L-lysine HCl (78%)	0.29	0.29	0.28	0.28
MDCP	1.60	1.60	1.68	1.68
Limestone	1.41	1.41	1.37	1.37
Vit. mix[2)]	0.10	0.10	0.10	0.10
Min. mix[3)]	0.10	0.10	0.10	0.10
Choline chloride	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Emulsifier[4)]	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition [4)]				
ME, kcal/kg	3,200.00	3,200.00	3,265.00	3,265.00
Crude protein, %	16.80	16.80	16.80	16.80
Total lysine, %	1.09	1.09	1.09	1.09
Total methionine, %	0.25	0.25	0.25	0.25
Calcium, %	0.90	0.90	0.90	0.90
Total phosphorus, %	0.70	0.70	0.70	0.70

[1)] Treatment : 1) basal diet : corn-SBM based diet (ME 3,265kcal/kg), 2) basal diet + 0.05% emulsifier, 3) basal diet – 65 kcal/kg of ME (ME 3,200 kcal/kg), 4) basal diet – 65 kcal/kg of ME + 0.05% emulsifier.

[2)] Provided per kg of diet : Vitamin A, 8,000 IU; Vitamin D_3, 1,600 IU; Vitamin E, 32 IU; d-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8mg; niacin, 16mg; vitamin B12, 12g; vitamin K, 2.4mg.

[3)] Provided per kg of diet : Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; CuSO4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[4)] Emulsifier : SOLMAX®50 (KIMIN INC., Korea)

[5)] Calculated value.

Table 2. Effects of exogenous hydrophilic emulsifier supplementation on body weight, back-fat thickness, feed intake and WEI in lactating sows

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
No. Sows		10	10	10	10				
Body weight, kg									
24 hrs postpartum		254.2	245.6	251.3	249.9	2.97	0.91	0.42	0.56
21 d lactation		243.7	235.1	242.8	245.1	3.38	0.52	0.65	0.44
BW changes (0-21 d)		-10.5	-10.5	-8.5	-4.8	1.50	0.21	0.57	0.55
Back-fat thickness, mm									
24 hrs postpartum		25.0	23.5	23.3	22.2	0.75	0.33	0.41	0.89
21 d lactation		22.8	22.1	21.6	21.1	0.68	0.41	0.66	0.94
BF changes (0-21 d)		-2.2	-1.4	-1.7	-1.1	0.44	0.72	0.47	0.90
Feed intake, kg/d		4.61	5.13	4.99	4.83	0.12	0.87	0.49	0.18
WEI, d		4.50	4.75	4.64	4.50	0.06	0.69	0.69	0.15

[1)] Standard error of mean.

Table 3. . Effects of exogenous hydrophilic emulsifier supplementation on reproductive performance and litter performance in lactating sows

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
No. Sows		10	10	10	10				
No. of piglets									
24 hrs postpartum		10.67	11.00	10.44	10.78	0.150	0.48	0.29	1.00
21d lactation		10.33	10.44	9.78	10.22	0.190	0.31	0.47	0.66
Litter weight, kg									
24 hrs postpartum		16.80	17.05	15.95	16.50	0.442	0.45	0.66	0.87
21d lactation		54.43	61.69	54.00	54.97	1.747	0.31	0.25	0.37
Weight gain (0-21d)		37.63	44.64	38.05	38.47	1.580	0.37	0.25	0.30
Piglet weight, kg									
24 hrs postpartum		1.58	1.55	1.52	1.53	0.031	0.54	0.86	0.76
21d lactation		5.26	5.92	5.49	5.36	0.134	0.52	0.31	0.14
Weight gain (0-21d)		3.68	4.38	3.97	3.83	0.126	0.60	0.26	0.10

[1)] Standard error of mean.

Table 4.1. Effects of exogenous hydrophilic emulsifier supplementation on blood profiles of lactating sows

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
Glucose, mg/dL									
24 hrs postpartum		-------------- 83.40 --------------							
21d lactation		69.50	70.25	64.00	68.25	2.794	0.55	0.69	0.78
Insulin, μU/mL									
24 hrs postpartum		-------------- 1.64 --------------							
21d lactation		2.88	1.50	2.28	2.65	0.355	0.71	0.51	0.26
Total protein, g/dL									
24 hrs postpartum		-------------- 6.90 --------------							
21d lactation		7.90	7.50	7.55	7.65	0.089	0.58	0.42	0.18
PUN, mg/dL									
24 hrs postpartum		-------------- 16.0 --------------							
21d lactation		16.83	21.15	17.58	16.85	0.717	0.17	0.17	0.06
Albumin, g/dL									
24 hrs postpartum		-------------- 4.26 --------------							
21d lactation		4.35	4.65	4.60	4.05	0.092	0.28	0.43	0.02
Creatinine, mg/dL									
24 hrs postpartum		-------------- 3.63 --------------							
21d lactation		2.27	2.64	2.50	2.33	0.095	0.85	0.63	0.20

[1)] Standard error of mean.

Table 4.2. Effects of exogenous hydrophilic emulsifier supplementation on blood profiles of lactating sows

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
Total cholesterol, mg/dL									
24 hrs postpartum		-------------- 27.40 --------------							
21d lactation		58.75	59.25	62.25	71.75	3.345	0.27	0.48	0.52
Triglyceride, mg/dL									
24 hrs postpartum		-------------- 18.60 --------------							
21d lactation		20.25	17.75	26.75	26.50	1.958	0.06	0.72	0.77
HDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 8.40 --------------							
21d lactation		24.50	27.50	27.50	32.50	2.029	0.36	0.36	0.82
LDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 16.80 --------------							
21d lactation		34.25	33.75	33.50	41.25	1.848	0.38	0.35	0.29
VLDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 3.80 --------------							
21d lactation		4.00	3.50	5.50	5.25	0.398	0.05	0.62	0.87
Free fatty acid, µEq/L									
24 hrs postpartum		-------------- 626.0 --------------							
21d lactation		242.5	157.0	208.3	215.8	19.06	0.76	0.33	0.25

[1)] Standard error of mean.

Table 5.1. Effects of exogenous hydrophilic emulsifier supplementation on blood profiles of piglets

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
Glucose, mg/dL									
24 hrs postpartum		-------------- 140.6 --------------							
21d lactation		108.5	94.0	121.0	116.7	5.540	0.13	0.41	0.65
Total protein, g/dL									
24 hrs postpartum		-------------- 5.86 --------------							
21d lactation		4.80	4.68	5.05	4.75	0.097	0.44	0.31	0.67
BUN, mg/dL									
24 hrs postpartum		-------------- 20.42 --------------							
21d lactation		9.05	8.28	8.68	7.63	0.669	0.73	0.55	0.93
Albumin, g/dL									
24 hrs postpartum		-------------- 1.15 --------------							
21d lactation		3.27	3.37	3.65	3.53	0085	0.15	0.94	0.52
Creatinine, mg/dL									
24 hrs postpartum		-------------- 0.726 --------------							
21d lactation		0.808	0.773	0.803	0.795	0.041	0.93	0.82	0.88

1) Standard error of mean.

Table 5.2. Effects of exogenous hydrophilic emulsifier supplementation on blood profiles of piglets

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Emulsifier, %	0	0.05	0	0.05		ME	E	MExE
Total cholesterol, mg/dL									
24 hrs postpartum		-------------- 64.20--------------							
21d lactation		131.50	149.5	188.75	186.25	10.69	0.03	0.70	0.61
Triglyceride, mg/dL									
24 hrs postpartum		-------------- 108.6 --------------							
21d lactation		133.5	70.75	102.0	95.5	10.89	0.87	0.12	0.20
HDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 19.80--------------							
21d lactation		66.50	57.25	74.50	86.75	4.694	0.04	0.86	0.23
LDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 25.80--------------							
21d lactation		60.25	85.25	117.0	106.0	9.941	0.06	0.71	0.35
VLDL - cholesterol, mg/dL									
24 hrs postpartum		-------------- 21.60-------------							
21d lactation		26.75	14.00	20.50	19.00	2.182	0.88	0.11	0.20
Free fatty acid, μEq/L									
24 hrs postpartum		-------------- 394.60 ------------							
21d lactation		628.00	486.50	570.75	624.75	41.76	0.65	0.63	0.28

[1)] Standard error of mean.

Table 6. Effects of exogenous hydrophilic emulsifier supplementation on milk composition in lactating sows

Item	ME, kcal/kg	3,200		3,265		SEM[1)]	P-value		
	Energy, %	0	0.05	0	0.05		ME	E	MExE
Casein, %									
24 hrs postpartum		-------------- 8.53 --------------							
21d lactation		4.40	4.49	4.42	4.42	0.045	0.80	0.66	0.62
Fat, %									
24 hrs postpartum		-------------- 8.24 --------------							
21d lactation		7.09	6.80	7.01	6.14	0.232	0.45	0.24	0.55
Protein, %									
24 hrs postpartum		-------------- 11.07 --------------							
21d lactation		4.91	5.06	8.24	5.02	0.062	0.86	0.54	0.61
Lactose, %									
24 hrs postpartum		-------------- 4.01 --------------							
21d lactation		6.04	6.16	6.01	6.07	0.031	0.34	0.20	0.62
Total solid, %									
24 hrs postpartum		-------------- 26.80 --------------							
21d lactation		19.52	19.43	19.28	18.64	0.079	0.27	0.43	0.55
Solid not fat, %									
24 hrs postpartum		-------------- 15.52 --------------							
21d lactation		11.06	11.25	11.05	11.16	0.079	0.77	0.38	0.82

[1)] Standard error of mean.

Chapter V : Effects of Exogenous Hydrophilic Emulsifier Supplementation on Apparent Ileal Nutrient Digestibility in Growing Pigs

ABSTRACT: This study was conducted to evaluate the effects of exogenous hydrophilic emulsifier supplementation on apparent ileal nutrient digestibility in growing pigs. A total of 9 crossbred growing pigs ([Yorkshire × Landrace] × Duroc, average body weight (BW) 22.95 ± 1.45kg) were allotted to each treatment in an individual metabolic crate to collect feces and urine separately in a completely randomized design (CRD) with 3 replicates per treatment. Treatments were 1) Control : corn-SBM based diet with 3% tallow (3,265 kcal of ME/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier. All other nutrients in experimental diet were met or exceeded the NRC requirement (1998). The experimental diets were provided twice daily at 07:00 and 19:00. In the results of the essential amino acids, the AID of lysine was increased as hydrophilic emulsifier level increased (linear, $P<0.01$). In addition, the AID of methionine and threonine were increased as hydrophilic emulsifier level increased (linear, $P=0.03$ and quadratic, $P=0.01$, respectively). However, the result in E0.05 treatment was differed significantly compared to that in control diet. Also, the AID of valine was increased as hydrophilic emulsifier level increased (quadratic, $P<0.01$) and the result in E0.05 treatment was significantly different compared to control treatment. The AID of saturated fatty acid was increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P=0.03$) and the results in E0.05 and E0.10 treatments had a highly significant difference compared to those in control treatment ($P<0.01$). Among the saturated fatty acids, the AID of myristic acid (C14:0) was increased as hydrophilic emulsifier level increased (linear, $P=0.04$; quadratic, $P=0.02$) and the results in E0.05 and E0.10 treatments had a significant difference compared to control treatment

($P=0.02$). The AID of palmitic acid (C16:0), heptadecanoic acid (C17:0) and stearic acid (C18:0) were increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P<0.01$). Regarding the AID of unsaturated fatty acids, there were no detectable effects on the AID except oleic acid (C18:1). The AID of oleic acid (C18:1) was increased as hydrophilic emulsifier level increased (quadratic, $P=0.02$) and the result in E0.05 treatment was significantly different compared to control treatment. Consequently, these results demonstrated that exogenous hydrophilic emulsifier supplementation improved the apparent ileal digestibility of amino acids and fatty acids, particularly essential amino acids and saturated fattty acids in growing pig.

Key words: Exogenous Hydrophilic Emulsifier, Apparent Ileal Nutrient Digestibility, Growing Pigs

INTRODUCTION

Fat was the important ingredient for pigs due to high energy value (Mayes, 2000). Generally, fat was often supplemented to commercial feeds to provide sufficient energy (Choi, 2014). Dietary fat improved growth performance and feed efficiency and modified the composition of body lipids in pigs (Stahly, 1984). Also supplementation of fats reduced the dust of feeds and improved palatability (Choi, 2014). The use of supplemental fats and oils as an energy source had become a wide spread practice in the feed industry (Gabbrielle, 2010), so fat digestion and absorption were very important in animal. But fat sources cannot be utilized as much as we want in animal diets due to the complicated process of fat digestion (Lee, 2016). The limitation of fat digestibility was controlled by many factors including ages, sex, environments, and species (Kussaibati *et al.,* 1982).

To improve fat digestibility in animals, various emulsifier products were introduced in the feed market. An emulsifier was a substance that stabilized an emulsion by increasing its kinetic stability and by reducing the surface tension (Choi, 2014). Structurally, an emulsifier consisted of a hydrophilic head and a lipophilic tail. The hydrophilic head was toward to the aqueous phase and the lipophilic tail to the oil phase. So its structural characteristic could help the fat digestion in animal body (Davis, 1990). Generally, as fat was insoluble in water, it cannot be digested easily without an emulsification process by bile salts. Therefore, when exogenous emulsifier was supplemented to the feed, dietary fat in the gastrointestinal tract changed to the smaller fat droplets and micelles, and then emulsifier could help to improving fat absorption efficiently. Although many studies were reported that dietary emulsifiers improved growth performance and nutrient digestibility in weaning pigs (Xing *et al*., 2004), there were very little studies the emulsifier's effects in growing pigs, especially in nutrient digestibility.

Therefore, the purpose of the current study was to determine the effects of exogenous hydrophilic emulsifier supplementation on apparent ileal nutrient digestibility in growing pigs.

MATERIALS AND METHODS

Experimental design and diet

A total of 9 crossbred growing pigs [(Yorkshire × Landrace) × Duroc] with average body weight 22.95 ± 1.45kg were allotted to each treatment in an individual metabolic crate to collect feces and urine separately in completely randomized design (CRD) with 3 replicates per treatment. Treatments were as followed: 1) Control : corn-SBM based diet with 3% tallow (ME 3,265 kcal/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier. All nutrients in experimental diet were met or exceeded the nutrient requirement of NRC (1998). The experimental diets were provided twice daily at 07:00 and 19:00. The formula and chemical composition of experimental diets were presented in Table 1.

Digestibility trial

Pigs took the surgery with injection of simple T-piece cannula. Following surgery, pigs were housed individually in metabolic cages (0.93 m x 1.53 m) for a recovery period of 2 weeks. Following the 2 weeks recovery period, experimental diets were introduced. Diets were fed for 7 days, with a 5 day period of diet adaptation, with collections of ileal digesta made on days 6 and 7. Cr_2O_3 was included in all diets as an indigestible marker. Daily feeding rates for the control diet were adjusted to three times maintenance (106 kcal of ME_m/kg $BW^{0.75}$; NRC 1998) provided twice a day every 07:00 and 19:00 and ileal digesta was collected twice a day every 08:00 and 20:00 at 6th and 7th day. Water was freely available via nipple drinkers. Apparent ileal digestibility was calculated for each diet and feces (Stein *et al*., 1998)

Calculation

Apparent ileal digestibility (AID,%) = 100 (［ND/NF］ × ［CrF/CrD］ × 100)

ND = nutrient % from ileal digesta

NF = nutrient % from feed
CrF = Cr % from feed
CrD = Cr % from ileal digesta

Chemical analysis

Collected digesta samples from each pig were put and sealed in plastic bags and kept frozen at -70C° until they were analyzed. And then, the samples were dried in an air-forced drying oven at 60C° for 72 h and weighted. Finally, they were ground into 1 mm particles in a Wiley mill for chemical analysis. Collected samples were analyzed for Cr_2O_3 (Williams *et al.,* 1962). Amino acid profiles in diets and digesta samples were quantified on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Fatty acid analysis was conducted according to Cruz-Hernandez *et al*. (2004).

Statistical analysis

The experimental data were analyzed using ANOVA and means were separated by least significant difference (LSD) test using PDIFF option in the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). The sample of individual pig was used as the experimental unit. Probability values less than 0.05 were considered as significant difference and highly difference at $P<0.01$. $0.05<P<0.10$ were indicated about some trend. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of emulsifier.

RESULTS & DISCUSSION

Apparent ileal digestibility (AID) on amino acids (AA)

Apparent ileal digestibility (AID) of amino acids was presented in Table 2. In the results of the essential amino acids, the AID of lysine was increased as hydrophilic emulsifier level increased (linear, $P<0.01$). In addition, the AID of methionine was increased as hydrophilic emulsifier level increased (linear, $P=0.03$). The AID of threonine was increased as hydrophilic emulsifier level increased (quadratic, $P=0.01$). However, the result in E0.05 treatment was differed significantly compared to that in control treatment. Also, the AID of valine was increased as hydrophilic emulsifier level increased (quadratic, $P<0.01$) and the result in E0.05 treatment was differed significantly compared to that in control treatment and it was not significant different compared to that in E0.10 treatment ($P<0.01$).

Dierick and Decuypere (2004) demonstrated that addition of emulsifier could improve amino acids digestibility in pigs. Imbeah and Sauer (1991) observed that ileal amino acids digestibility in growing-finishing pigs was increased with dietary fat supplementation. Li and Sauer (1994) reported that the AID of CP in weaning pigs was increased linearly with increasing fat content. Kil and Stein (2011) indicated that addition of soybean oil or choice white grease improved the AID of AA in growing pigs. This improvement in the AID of AA was related to slower gastric emptying (Low *et al*., 1985) and delayed transition of digesta flow (Valaja and Siljander-Rasi, 2001) due to dietary fat in gastrointestinal tract of pigs. The reduced passage rate was likely to increase the time for protein digestion and AA absorption (Li and Sauer, 1994). For these reasons, supplementation of emulsifier improved the apparent ileal digestibility of amino acids in growing pigs.

Apparent ileal digestibility (AID) on fatty acids (FA)

The results of apparent ileal digestibility (AID) of fatty acids (FA) in growing pigs were shown in Table 3.

The AID of saturated fatty acid was increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P=0.03$) and the results in E0.05 and E0.10 treatment had a highly significant difference compared to those in control diet ($P<0.01$). Among the saturated fatty acid, the AID of myristic acid (C14:0) was increased as hydrophilic emulsifier level increased (linear, $P=0.04$; quadratic, $P=0.02$) and the results in E0.05 and E0.10 treatments had a significant difference compared to those in control treatment ($P=0.02$). The AID of palmitic acid (C16:0) and heptadecanoic acid (C17:0) were increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P<0.01$) and the results in E0.05 and E0.10 treatments had a highly significant difference compared to those in control treatment ($P<0.01$). The AID of stearic acid (C18:0) was increased as hydrophilic emulsifier level increased (linear, $P<0.01$; quadratic, $P=0.01$) and the results in E0.05 and E0.10 treatments had a highly significant difference compared to those in control treatment ($P<0.01$). Regarding the AID of unsaturated fatty acids, there were no detectable effects on the AID except oleic acid (C18:1). The AID of oleic acid (C18:1) was increased as hydrophilic emulsifier level increased (quadratic, $P=0.02$) and the result in E0.05 treatment was differed significantly compared to that in control treatment and it was not significant different compared to that in E0.10 treatment ($P=0.03$).

Kil *et al*. (2010) reported that both AID of fat and ATTD of fat increased as dietary level of fat was increased. Also they demonstrated that apparent digestibility of extracted fat was higher than intact fat. This result was agreed with previous data that apparent digestibility of extracted fat was higher than that of intact fat for soybean products (Agunbiade *et al*., 1992). Frobish (1970) observed that apparent digestibility of fat increased with an increase in age and with addition of fat to the diet. Cho *et al*. (2008) demonstrated the effects of fat source and fat level on ATTD and AID of DM, GE, N and crude fat in pigs. Therefore, supplementation of emulsifier in growing pig diet had positive influence on apparent ileal digestibility of fatty acid by helping the digestion of fat of fatty acid.

CONCLUSION

This experiment represented that exogenous hydrophilic emulsifier supplementation in growing pig diets improved the apparent ileal digestibility of amino acids, especially in lysine and methionine. Also exogenous hydrophilic emulsifier supplementation in growing pig diets improved the AID of saturated fatty acid. Consequently, these results demonstrated that exogenous hydrophilic emulsifier supplementation contributed positive effects on AID of essential amino acids and saturated fatty acids in growing pigs.

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Table 1. The formulas and chemical composition of experimental diet

Item	Treatment[1)]		
	Control	E0.05	E0.10
Ingredients, %			
Corn	41.92	41.99	42.08
SBM-46	16.18	16.22	16.24
Wheat bran	2.75	2.59	2.43
Rapeseed meal	3.59	3.59	3.59
Corn gluten meal	3.01	3.01	3.01
Wheat	26.35	26.35	26.35
Tallow	3.00	3.00	3.00
DCP	1.33	1.33	1.33
Limestone	0.59	0.59	0.59
L-lysine HCL	0.28	0.28	0.28
Vit. mix[2)]	0.10	0.10	0.10
Min. mix[3)]	0.10	0.10	0.10
Salt	0.30	0.30	0.30
Chrome oxide	0.50	0.50	0.50
Emulsifier[4)]	0.00	0.05	0.10
Total	100.00	100.00	100.00
Chemical composition[5)]			
ME, kcal/kg	3265.00	3265.04	3265.00
Crude protein, %	18.00	18.00	18.00
Total lysine, %	0.95	0.95	0.95
Total methionine, %	0.32	0.29	0.29
Calcium, %	0.60	0.60	0.60
Total phosphorus, %	0.50	0.50	0.50

[1)] Control : corn-SBM based diet with 3% tallow (ME 3,265 kcal/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier.

[2)] Provided per kg of diet: Vit A, 16,000IU; Vit D3, 3,200IU; Vit. E, 35IU; Vit. K3, 5mg; Rivoflavin, 6mg; Calcium, pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B12, 20ug.

[3)] Provided per kg of diet: Fe, 281mg; Cu, 288mg, Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

[4)] SOLMAX®50, KIMIN INC., Korea

[5)] Calculated value.

Table 2. Effects of hydrophilic emulsifier supplementation on apparent ileal digestibility of amino acids in growing pigs

Item	Treatment[1)]			SEM[2)]	*P*-value		
	Control	E0.05	E0.10		Treatment	Linear	Quadratic
CP	89.45	92.47	86.76	1.196	0.09	0.22	0.05
Essential amino acids							
Arg	92.43	94.11	92.52	0.427	0.31	0.34	0.15
His	91.98	93.33	92.00	0.398	0.45	0.99	0.23
Ile	89.30	88.93	88.22	0.391	0.59	0.34	0.85
Leu	91.92	92.78	91.24	0.333	0.19	0.37	0.11
Lys	89.37	91.66	92.32	0.498	<0.01	<0.01	0.11
Met	91.82	92.92	93.70	0.326	0.07	0.03	0.76
Phe	91.44	92.98	91.93	0.331	0.19	0.51	0.10
Thr	83.94[b]	87.43[a]	85.68[ab]	0.547	0.02	0.07	0.01
Val	87.70[B]	89.24[A]	87.87[B]	0.254	<0.01	0.26	<0.01

[1)] Control : corn-SBM based diet with 3% tallow (ME 3,265 kcal/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier.
[2)] Standard error of the mean.
[ABC] Means with different superscripts in the same row significantly differ (P<0.01).
[abc] Means with different superscripts in the same row significantly differ (P<0.05).

Table 3. Effects of hydrophilic emulsifier supplementation on apparent ileal digestibility of fatty acids in growing pigs

Criteria	Treatment[1)]			SEM[2)]	*P*-value		
	Control	E0.05	E0.10		Treatment	Linear	Quadratic
Total FA	87.57	92.13	92.30	1.021	0.08	0.05	0.21
Saturated FA	85.60^{B}	93.45^{A}	93.14^{A}	1.463	<0.01	<0.01	0.03
Myristic(C14:0)	90.91^{b}	96.58^{a}	94.49^{a}	0.899	0.02	0.04	0.02
Palmitic(C16:0)	81.32^{C}	89.72^{A}	86.26^{B}	1.274	<0.01	<0.01	<0.01
Heptadecanoic(C17:0)	75.05^{B}	92.03^{A}	87.35^{A}	2.585	<0.01	<0.01	<0.01
Stearic(C18:0)	69.07^{B}	89.03^{A}	85.64^{A}	3.267	<0.01	<0.01	0.01
Unsaturated FA	88.44	91.53	91.90	0.886	0.27	0.15	0.47
Palmitoleic(C16:1)	99.29	99.40	99.17	0.049	0.09	0.19	0.06
Oleic(C18:1)	86.78^{b}	91.16^{a}	88.85^{ab}	0.729	0.03	0.10	0.02
Linoleic(C18:2)	78.30	81.24	75.39	1.408	0.35	0.45	0.22
Linolenic(C18:3)	85.39	86.70	82.07	0.928	0.13	0.14	0.13

[1)] Control : corn-SBM based diet with 3% tallow (ME 3,265 kcal/kg), 2) E0.05 : basal diet + 0.05% emulsifier (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : basal diet + 0.10% emulsifier.
[2)] Standard error of the mean.
[ABC] Means with different superscripts in the same row significantly differ (*P*<0.01).
[abc] Means with different superscripts in the same row significantly differ (*P*<0.05).

Chapter VI. Overall Conclusion

Recently, the effect of various emulsifiers has been demonstrated in the pig. However, most emulsifiers were lipophilic emulsifier and a few experiments were conducted to evaluate the effects of hydrophilic emulsifier supplementation in pigs. Therefore, three experiments were conducted to investigate 1) the effects of exogenous hydrophilic emulsifier supplementation on growth performance, blood profiles and nutrient digestibility in weaning pigs, 2) the effects of exogenous hydrophilic emulsifier supplementation on reproductive performance, litter performance and blood profiles in lactating sows and 3) the effects of exogenous hydrophilic emulsifier supplementation on apparent ileal nutrient digestibility in growing pigs.

The supplementation of hydrophilic emulsifier to weaning pig diet improved ADG and G:F ratio, and increased crude fat digestibility. The supplementation of hydrophilic emulsifier to lactating sow diet showed positive effects on piglet weight gain in lactating sows by improving fat digestibility when low energy diet of 3,200 kcal of ME/kg was provided. The supplementation of hydrophilic emulsifier in diet of growing pig improved the apparent ileal digestibility of amino acids and fatty acid, particularly essential amino acids and saturated fattty acids.

These results implied that hydrophilic emulsifier could be supplemented in swine diet to improve the growth performance and fat digestibility.

Chapter VII. Summary in Korean

본 실험은 양돈사료 내 친수성 유화제의 첨가효과를 규명하기 위해 시행되었다. 총 3개의 실험으로 구성되어있는데, 1) 이유자돈 사료 내 친수성 유화제의 첨가가 이유자돈의 성장성적, 혈액성상, 영양소 소화율에 미치는 영향, 2) 포유모돈 사료 내 친수성 유화제의 첨가가 체형변화, 번식성적, 포유성적, 혈액성상, 유성분에 미치는 영향, 3) 육성돈 사료 내 친수성 유화제의 첨가가 육성돈의 외관상 회장소화율에 미치는 영향을 평가하기 위해 수행되었다.

Experiment I. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Growth Performance, Blood Profiles and Nutrient Digestibility in Weaning Pigs

본 연구는 이유자돈 사료 내 친수성 유화제의 첨가가 이유자돈의 성장 성적, 혈액 성상 및 영양소 소화율에 미치는 영향을 규명하기 위해서 수행되었다. 28±3일령에 이유한 평균 체중 7.22 ± 0.23 kg인 삼원 교잡종 ([Yorkshire × Landrace]) × Duroc) 이유자돈 80두를 공시하였으며, 4처리 5반복, 반복 당 4마리씩 성별과 체중에 따라 난괴법 (RCBD; Randomized complete block design)으로 배치하여 실험을 수행하였다. 실험의 처리구는 유화제 수준에 따라 구분하였으며, 1) Control : 옥수수-대두박 위주의 기초사료 (ME 3,265 kcal/kg), 2) E0.05 : 기초사료 + 유화제 0.05% 첨가(SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : 기초사료 + 유화제 0.10% 첨가, 4) E0.15 : 기초사료 + 유화제 0.15% 첨가로 구성되었다. 총 5주간의 실험사료는 자돈의 성장단계에 따라 미국사양표준의 영양소 요구량 (NRC,1998)을 고려하여 배합되었으며, Phase I (이유후 0-2주)은 에너지가

3,265 kcal of ME/kg이며, CP 23.70% 이었고, Phase II (이유후 3-5주)는 에너지가 3,265 kcal of ME/kg이고, CP 20.90%를 각각 포함하는 사료이다. 사료와 물의 자유 급이 (*ad libitum*)가 가능하고 온도 조절이 용이한 무창돈사에서 사육되었으며, 체중 및 일당증체량과 사료효율을 조사하기 위하여 2주차와 5주차에 체중과 사료 섭취량을 측정하였다. 실험 결과, Phase I (이유후 0-2주)에서는 성장성적의 유의적인 차이가 나타나지 않았다. 그러나 일당증체량에 있어 유화제 함량이 증가함에 따라 linear하게 증가하였으며 (P=0.01), G:F ratio의 경우 전체 시험기간 (0-5주)에서 유화제 함량이 증가함에 따라 linear하게 증가하였으며 (P<0.01), Phase II (이유후 3-5주) 동안의 G:F ratio가 유화제를 첨가한 처리구들에서 대조구에 비해 통계적 유의차가 나타났다 (P=0.02). 혈액 성상을 분석한 결과, Phase II (이유후 3-5주)의 혈중 총콜레스테롤과 HDL, LDL-콜레스테롤의 농도에 있어 유화제 함량이 증가함에 따라 quadratic 효과가 나타났으며 (P<0.01), E0.10 처리구에서 다른 처리구보다 총콜레스테롤 (P<0.01), LDL (P<0.01), HDL-콜레스테롤 (P=0.02)의 농도에 감소하는 결과가 나타났다. 영양소소화율에 있어서 유화제의 첨가로 인해 건물, 조단백질, 조회분의 소화율은 처리구간의 통계적인 유의차가 나타나지 않은 반면, 유화제 함량이 증가함에 따라 조지방 소화율에서 quadratic 효과가 나타났으며 (P=0.01), 유화제를 사용한 처리구에서 처리구간 고도의 통계적인 유의차가 나타났다 (P<0.01). 결론적으로 자돈 사료 내 친수성 유화제의 첨가는 성장성적에 있어 긍정적인 효과가 있으며, 특히 G:F ratio와 지방소화율을 향상시키는데 있어 긍정적인 효과를 기대할 수 있다.

Experiment II. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Reproductive Performance, Litter Performance and Blood Profiles in Lactating Sows

본 연구는 포유돈 사료 내 친수성 유화제의 첨가가 포유모돈 및 포유자돈에 미치는 영향을 알아보기 위해 수행되었다. 실험은 임신이 확인된 평균체중 248.6 ± 19.71 kg, 평균 6 산차의 F1 교잡종 (Yorkshire × Landrace) 경산 모돈 40 두를 공시하여, 체중과 등지방 두께 및 복당체중에 따라 4 개 처리구에 완전임의배치법 (CRD; completely randomized design)로 구배치하여 수행되었다. 실험설계는 2×2 factorial arrangement design 으로 구성하였으며, 요인 1 은 사료 내 에너지수준 ME 3,265 kcal/kg 과 ME 3,200 kcal/kg 으로 설정하였으며 요인 2 는 유화제 SOLMAX®50 의 0.05% 첨가유무로 설정하였다. 3 주간의 포유성적 및 포유자돈의 성장성적을 측정한 결과, 포유자돈의 증체량(0-21d)에서는 에너지요인과 유화제요인의 상호작용의 경향이 나타났다 (ME×E interaction, P=0.10). 고에너지수준(ME 3,265 kcal/kg)에서는 유화제 첨가시 포유자돈의 증체량은 차이가 없었지만, 저에너지수준(ME 3,200 kcal/kg)에서 유화제 첨가시 포유자돈의 증체량이 증가하였다. 모돈의 혈중 PUN 농도와 albumin 농도에서도 에너지와 유화제 요인간의 상호작용(interaction)이 나타났으며 (MExE interaction, P=0.06, P=0.02), 고에너지수준 (ME 3,265 kcal/kg)일때는 유화제 첨가시 PUN 과 albumin 농도에 차이가 없었으나, 저에너지수준 (ME 3,200 kcal/kg)에서는 유화제 첨가시 PUN 과 albumin 농도가 높아지는 경향이 나타났다. 모돈의 혈중 지방성분의 농도를 조사해본 결과, 에너지 요인에 따라 triglyceride 농도에서 유의적 경향이 나타났으며 (Energy, P=0.06), 고에너지수준 (ME 3,265 kcal/kg)일 때 triglyceride 의 농도가 저에너지수준 (ME 3,200 kcal/kg)에 비해 높은 결과가 나타났다. VLDL-cholesterol 에서도 에너지요인에서 유의적 경향이 나타났으며 (Energy, P=0.05), 고에너지수준 (ME 3,265 kcal/kg)일 때 VLDL-cholesterol 의 농도가 저에너지수준 (ME

3,200 kcal/kg)에 비해 높은 결과가 나타났다. 포유자돈의 혈중 glucose, BUN, total protein, albumin, creatinine 농도에서는 처리구간에 통계적인 유의차가 나타나지 않았다. 포유모돈의 유성분 또한 처리구간의 통계적인 유의차가 나타나지 않았다. 결론적으로 포유돈 사료 내 유화제의 첨가는 저에너지수준 (ME 3,200kcal/kg) 일 때 포유자돈의 증체량에 긍정적인 효과가 있는 것으로 사료된다.

Experiment III. Effects of Exogenous Hydrophilic Emulsifier Supplementation on Apparent Ileal Nutrient Digestibility in Growing Pigs

본 연구는 사료 내 친수성 유화제의 첨가가 육성돈의 외관상 회장 소화율에 미치는 영향에 대하여 알아보기 위하여 수행되었다. 평균 체중 22.95 ± 1.45 kg 의 3 원 교잡종 ([Yorkshire × Landrace]) × Duroc) 육성돈 9 두를 3 처리 3 반복, 반복 당 1 두씩 체중에 따라 완전임의배치법 (CRD; completely randomized design)으로 배치하여 실험을 수행하였다. 실험 처리구는 유화제의 수준에 따라 구분하였으며, 1) Control : 3,265 kcal of ME/kg 의 옥수수, 대두박 위주의 우지(tallow) 3%가 포함된 기초사료, 2) E0.05 : 기초사료 + 0.05% 유화제 (SOLMAX®50, KIMIN INC., Korea), 3) E0.10 : 기초사료 + 0.10% 유화제로 구성하였다. 실험사료의 영양소 함량은 미국 사양표준의 영양소 요구량 (NRC, 1998)을 고려하여 배합되었다. 육성돈 외관상 회장소화율 실험 결과, 사료 내 유화제 함량이 증가함에 따라, 필수 아미노산중, lysine 과 methionin 의 소화율이 유화제 함량이 증가함에 따라 linear 하게 증가하였다 (linear, $P<0.01$, $P=0.03$). 또한 threonine 과 valine 소화율에서 유화제 함량이 증가함에 따라 quadratic 효과를 보였다 (quadratic, $P=0.01$, $P<0.01$). Threonine

소화율의 경우 E0.05 처리구가 대조구와 비교했을 때 유의적인 차이를 보였고, E0.10 처리구와 비교했을 때 유의적인 차이가 나타나지 않았다(P=0.02). Valine 소화율의 경우 E0.05 처리구가 대조구와 비교했을 때 유의적인 차이를 보였고, E0.10 처리구와 비교했을 때 유의적인 차이가 나타나지 않았다(P<0.01). 지방산 소화율에 있어, 포화지방산의 경우 유화제 함량이 증가함에 따라 linear 효과 (P<0.01)와 quadratic 효과 (P=0.03)가 나타났고, E0.05 와 E0.10 처리구 모두에서 포화지방산 소화율이 대조구와 비교해 상당한 유의적인 차이가 나타났다 (P<0.01). 특히 포화지방산 중 myristic acid 은 유화제 함량이 증가함에 따라 linear 효과 (P=0.04)와 quadratic 효과 (P=0.02)가 나타났고, E0.05 와 E0.10 처리구 모두에서 대조구와 비교해 유의적인 차이가 나타났다 (P=0.02). Palmitic acid 과 heptadecanoic acid 의 경우 유화제 함량이 증가함에 따라 linear 효과 (P<0.01)와 quadratic 효과 (P<0.01)가 나타났고, E0.05 와 E0.10 처리구 모두에서 대조구와 비교해 상당한 유의적인 차이가 나타났다 (P<0.01). Stearic acid 의 소화율에서 유화제 함량이 증가함에 따라 linear 효과 (P<0.01)와 quadratic 효과 (P=0.01)가 나타났고, E0.05 와 E0.10 처리구 모두에서 대조구와 비교해 상당한 유의적인 차이가 나타났다 (P<0.01). 불포화지방산 중 oleic acid 소화율에서 유화제 함량이 증가함에 따라 quadratic 효과를 보였고 (quadratic, P=0.02), E0.05 처리구가 대조구와 비교했을 때 유의적인 차이를 보였고, E0.10 처리구와 비교했을 때 유의적인 차이가 나타나지 않았다 (P=0.03). 결론적으로 육성돈에서 지방원료가 포함된 사료에 유화제의 첨가는 아미노산과 지방산의 외관상 회장소화율을 개선시켜 이용효율을 높여준다.